THE HAWAIIAN
PLANTERS' RECORD

Vol. XXXVII FOURTH QUARTER, 1933 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Research and Government Economy:

We reproduce a statement on the importance of research in relation to government economy, as presented on the floor of Congress in Washington.

Biology of an Important Armyworm Parasite:

The nutgrass armyworm has been uncommon during the past year and a half The habits of the latest parasite in Hawaii of this armyworm are described, and its method of attack illustrated from life, together with drawings of some of the developmental stages of this imporant enemy of one of our conspicuous cane pests.

Measuring Temperatures in Terms of Day-Degrees:

The paper shows how to calculate accumulated day-degrees for any crop year from the data on temperature and areas under cultivation. The basic assumptions underlying the methods are also discussed briefly.

A Basic Fertilizer Plan and Schedule:

With the increased interest in differential fertilization for fields and parts of fields, a basic fertilizer plan and schedule is suggested, together with guides for deviating from same. The actual figures offered with this plan are approximations: suggestive rather than absolute, and they should thus be interpreted and used.

Phosphate Fixation in Hawaiian Soils:

A resumé is given of the researches by staff members upon the subject of Phosphate Fixation in Hawaiian Soils. A discussion is offered bearing upon the apparent association of soil colloids with the phenomenon of fixation. Examples are cited of a few common colloidal substances. A detailed account of a greenhouse experiment is described in which cane was successfully grown with insoluble phosphates. Practical suggestions are offered as a means of minimizing or bypassing the fixation by the soil of applied phosphate fertilizer.

The rate of fixation is considered particularly in reference to the period of time elapsing before complete fixation takes place and during which period the plant roots may have opportunity to absorb adequate quantities of phosphatic nutrient.

A discussion is offered bearing upon the matter of equilibrium between the phosphate in the fixed reserve and that residing in the soil solution. Other topics referred to embrace the relationships of base exchange to fixation, the employment of fertilizer briquettes, the marked contrast of the degree of fixation in surface and subsoils, the geographic variability of the phenomenon, and the importance of employing a form of phosphate fertilizer most appropriate to the soil conditions in which the crop will be grown.

Variation of Mineral Content of Sugar Cane with Age and Seasons:

Results and discussion are given relative to an investigation of changes which occur in the mineral composition of the sugar cane plant with age and season. Monthly examination was made of various parts of the plant between the ages of one and twenty-four months. Figures illustrating the observed changes are presented.

Water:

We would commend for careful reading the address delivered before the Hawaiian Academy of Science by its retiring President, C. S. Judd. In this address the speaker, in clear and convincing statements cast in a pleasing style, tells the story of water; the material which made possible the origin and continuation of life on the earth and the development of man and his agriculture and arts. He calls attention to the numerous losses which civilization sustains through floods and erosion and argues for watershed protection to conserve water, land and the fertility of the soil.

In criticizing the Hoyt and Troxell report, the obvious purpose of which is to prove that "forests do not conserve the water supply," Mr. Judd displays charity and restraint when he uses no stronger language than "the lamentable inadequacy of the report," "the report presents an amazingly unbalanced picture of the many sided water problem," and "the lack of adequate analysis and evaluation of the several factors that account for relatively small increase of summer flow invalidates both conclusions and deductions of their report."

In their report, Hoyt and Troxell carefully avoid consideration of one factor which was in large part responsible for the results obtained. Consideration of this factor lies in the field of the engineer rather than in that of the forester—and the authors are engineers. One of the most obvious and best-known features attributable to a forest cover as a restrainer of surface run-off is the penetration of the soil by plant roots which open up avenues along which water may pass from the surface into underground channels. The cutting off of a forest may remove the vegetation above the surface of the ground, but it leaves the roots in the ground with their attending channels in the soil. These channels continue to function after the trees have disappeared and for many years the slow decay of the roots constantly improves their water-conducting capacity.

In the so-called "Wagon-Wheel-Gap Experiment," the forest cover was removed, thus adding to run-off the water formerly consumed by the trees and, at the same time, retaining on the watershed one of the most effective features created by the forest for the diversion of water from the surface into underground channels.

Mayor Laguardia On Research*

The election of Major Laguardia as mayor of New York City gives interest to his record in support of scientific research. As a member of the seventy-second Congress, speaking on December 28, 1932, in opposition to eliminate an item of approximately $39,000 from the agricultural appropriation bill, he said in part:

"Mr. Chairman: Science knows no politics. Are we in this frenzy of economy, brought about by those who control the wealth of this country, seeking to put a barrier on science and research for the paltry sum of $39,113 out of an appropriation of $100,000,000? Science will go on when existing political parties will long have been forgotten.

"I am sorry that the distinguished leader of the Republican Party in the House states that he is not versed in botany and publicly admits that he does not know anything of these terms or what it is all about; but, Mr. Chairman, it is indeed a sad day for the people of this country when we must close the doors of the laboratories doing research work for the people of the United States. The gentleman from New York says it is all foolish.

"Yes; it was foolish when Burbank was experimenting with wild cactus. It was foolish when the Wright boys went down to Kitty Hawk and had a contraption there that they were going to fly like birds. It was foolish when Robert Fulton tried to put a boiler into a sail boat and steam it up the Hudson. It was foolish when one of my ancestors thought the world was round and discovered this country that the gentleman from New York could become a Congressman. (Laughter.) . . . Do not seek to stop progress; do not seek to put the hand of politics on these scientific men who are doing a great work. As the gentleman from Texas points out, it is not the discharge of these particular employees that is at stake, it is all the work of investigation, of research, of experimentation that has been going on for years that will be stopped and lost."

The next day, when another item in the same bill was under consideration and the point was made that research in agriculture might well be curtailed because of current overproduction, Major LaGuardia said further:

"I want to say to my colleague, the gentleman from New York, that I believe he is confusing the purpose of experimentation and research work of this kind with the immediate question of production. Surely we can not delay scientific research until the time comes when this country will need greater production. That indeed would be lack of vision. The very purpose of this kind of investigation and study is to have the information complete and ready when it is wanted, for it can not be developed overnight. . . . .

"Momentary overproduction is not the important question. The important question is the continuing of study to correct the defects of nature. The most fascinating part of human activity is its constant combat with nature in fighting the elements and in correcting the defects of nature. This has engaged the attention of mankind from the earliest times of which we have record. Assuming, if you please, that we now have overproduction and production of more commodities than the people of the country have ability to purchase, that is no justification for closing the doors of these laboratories, closing the doors to scientific research and stopping it. We must continue it. The population is constantly increasing. Some day the legislative branch of government will keep abreast of science. Why, Mr. Chairman, the most humble research scientist in the Department of Agriculture is at this time contributing more to his country than the most useful Member of Congress. The most humble engineer in the General Electric Laboratory or the Radio Corporation of America Laboratory is more useful to humanity than the most brilliant orator of this House. The trouble is that the legislative branch of government has not kept abreast with science. Government has lagged, science has advanced. We have permitted an unbalanced system of distribution to continue while science has increased

* *Science*, Vol. LXXVIII, pp. 509-10, 1933.

production. We are living in the paradoxical state where there is great overproduction on the one hand and want and misery on the other. This is not the fault of science. This is the fault of government. This is the fault of men who have control of the governmental affairs of the country.

"I want to plead with my colleague, the gentleman from New York (Mr. Taber), in his eagerness—and he is sincere and works hard on these bills—not to be too hasty in cutting down these appropriations to continue this scientific work, so that when the time does come we will have the information available. I repeat, if the science of government had only advanced along with the progress made in electricity, chemistry, mechanics, transportation and agriculture, we should not today find ourselves in the midst of a ruinous financial crisis. While science and the arts and mechanics were progressing, government was struggling along with laws and economics founded on principles accepted centuries ago. Today we are still endeavoring to struggle along under construction and limitations of a constitution drafted and accepted at a time when steam had not yet been applied, before the railroads, before the telegraph, when electricity was entirely unknown, and in the days of hand production. Yes, gentlemen, science has forged ahead, and nothing that ignorance, petty politics, lack of vision, or hope to continue the old system may try to do can stop the onward march of science. So let not Congress seek to mitigate its shortcomings by attempting to adjust the universe with its own snail-like pace."

[H. L. L.]

Notes on the Biology of *Telenomus nawai* Ashm., An Important Parasite of the Armyworm *Spodoptera mauritia* (Boisd.)

By C. E. Pemberton

INTRODUCTION

During the last week of September, 1926, J. S. Rosa observed a minute black parasite on a cluster of eggs of the grass armyworm *Spodoptera mauritia* at the Experiment Station, H. S. P. A., in Honolulu. Suspecting this wasp to be an actual parasite of the eggs of the moth and possibly new to Hawaii, he saved the egg-cluster and on October 4, the following week, a number of identical parasites hatched from the eggs. His surmise proved correct, for upon examination O. H. Swezey found the parasite to be a species of Telenomus, a Scelionid not previously known in Hawaii (1), and subsequent study by A. B. Gahan, of the U. S. Bureau of Entomology, of specimens sent him by Mr. Swezey, revealed that the wasp was *Telenomus nawai* Ashm. (2). This parasite was first discovered by Y. Nawa in Gifu, Japan, in 1904, where it was found developing in eggs of an unknown moth. It was named and described the same year (3).

Following Mr. Rosa's discovery of the parasite, various entomologists of the Experiment Station staff soon found it parasitizing Spodoptera eggs in many parts of Honolulu. Mr. Rosa began breeding it for distribution to all of the islands in October, 1926, and by May, 1928, about 275,000 were reared and distributed. In March, 1928, Mr. Swezey found it established on Kauai. In April, 1929, Dr. F. X. Williams recovered specimens at Pioneer Mill Company, Maui. During March, 1930, Mr. Swezey found it on Molokai and in October, 1931, Dr

Williams found it parasitizing the moth eggs at Hutchinson Sugar Plantation Company on Hawaii. It has since been abundantly found at many locations and is thus well established on all of the main islands of the group.

This important armyworm parasite reached the islands accidentally and was not intentionally introduced, nor was it known to be of importance in Japan before it demonstrated its value here after becoming established. We can only conjecture as to how it reached Hawaii. It must have emerged from some moth eggs from Japan or the South Pacific after those eggs had reached Hawaii, but to our knowledge no new moth pest arrived with them. These eggs could have been on ornamental plants commonly carried on many ships stopping at Honolulu, or the parasites could have emerged from moth eggs plastered on a ship's woodwork or on packing cases discharged in Honolulu, or in many other situations, since many moths are not particular where they place their eggs. As this parasite has been reared from the eggs of another moth (*Prodenia litura* Fabr.) by H. W. Simmonds (4), at Levuka, Fiji (1925), it may very possibly have reached Hawaii from the Fiji group rather than Japan.

To date, *Telenomus nawai* has been found to parasitize only the eggs of our so-called nutgrass armyworm *Spodoptera mauritia*. Mr. Swezey (5) attempted to rear it on the eggs of various Lepidoptera but succeeded only when using *Spodoptera mauritia* eggs.

During March, April and May, 1933, the writer had opportunity to make some studies of the biology of this parasite. The salient features of its life habits are given below. Mr. Rosa has added much to our knowledge of the parasite. During the two and one-half years of breeding it for distribution to plantations he compiled some interesting notes. These are included.

Oviposition

The female parasite begins ovipositing in moth eggs almost immediately after hatching if eggs can be found. Freshly laid eggs are preferred. W. Twigg-Smith has obtained some excellent magnified photographs from life of a number of these parasites in the act of stinging a mass of Spodoptera eggs and laying their own eggs within them, as shown in Fig. 1. The parasite requires but a few seconds to force its ovipositor into a moth egg. It then remains almost motionless usually for 40 or 50 seconds, during which time its own egg is passed from its body down through the ovipositor and into the interior of the host egg. The ovipositor is then quickly withdrawn and cleaned for about 5 to 30 seconds between the hind tarsi or feet. The parasite then immediately moves to the next or nearby egg and repeats the operation. One parasite was kept under observation when ovipositing over an egg mass on April 30, 1933, for one and one-half hours. During this time, 62 moth eggs were stung and apparently parasitized before the parasite crawled off of the egg mass and ceased operations. This is the usual procedure. Sometimes fewer eggs are laid at any given period before the parasite stops to rest and sometimes more. The moth eggs are often laid in layers two or three tiers thick. In such cases the parasite has no difficulty forcing its small body or narrow abdomen down between the layers to reach the eggs at the bottom.

Occasionally two parasites will be seen stinging and laying into the same moth egg. Dissection of this egg will usually show that two parasite eggs have been

deposited, but after further study it was found that only one parasite ultimately developed. Mr. Rosa has segregated many individual parasitized eggs into separate vials and never did more than one parasite ever issue from such eggs.

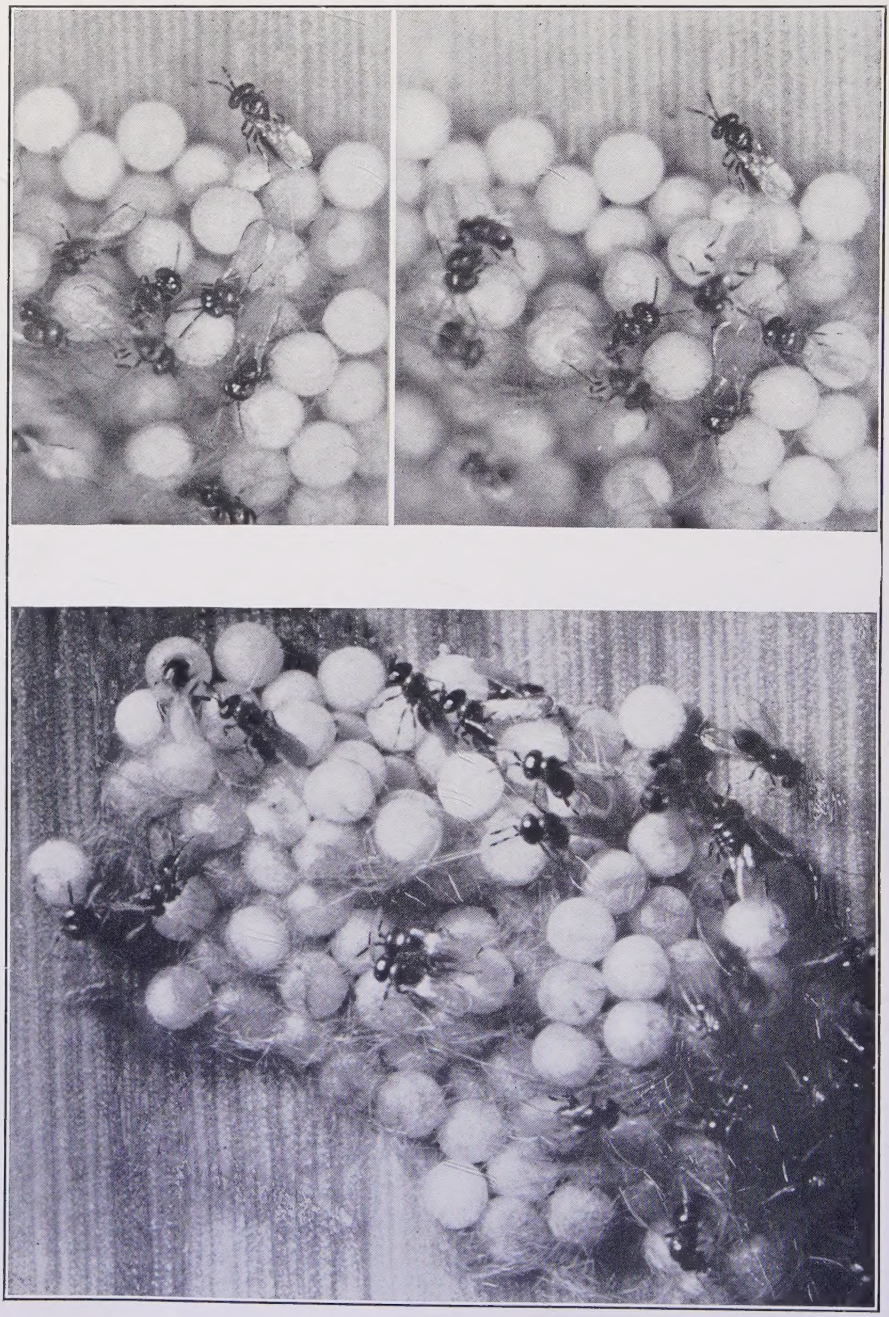


Fig. 1. Magnified photos from life showing *Telenomus nawai* females actually ovipositing in eggs of the armyworm *Spodoptera mauritia*.

Dissection of the ovaries of freshly hatched females usually show about 63 to 84 mature eggs present. Each parasite is thus capable of parasitizing at least that many moth eggs. Records on the total number of progeny possible for 10 individual parasites which Mr. Rosa kept under observation during February and March, 1928, ranged from 16 to 132 per parasite with an average of 89. In each case the parasite laid all of its eggs during the first few days of its life and never after the seventh day. Parasites can, however, be kept alive indoors in glass tubes and fed honey and water for from 10 to 20 days if given no chance to attack Spodoptera eggs.

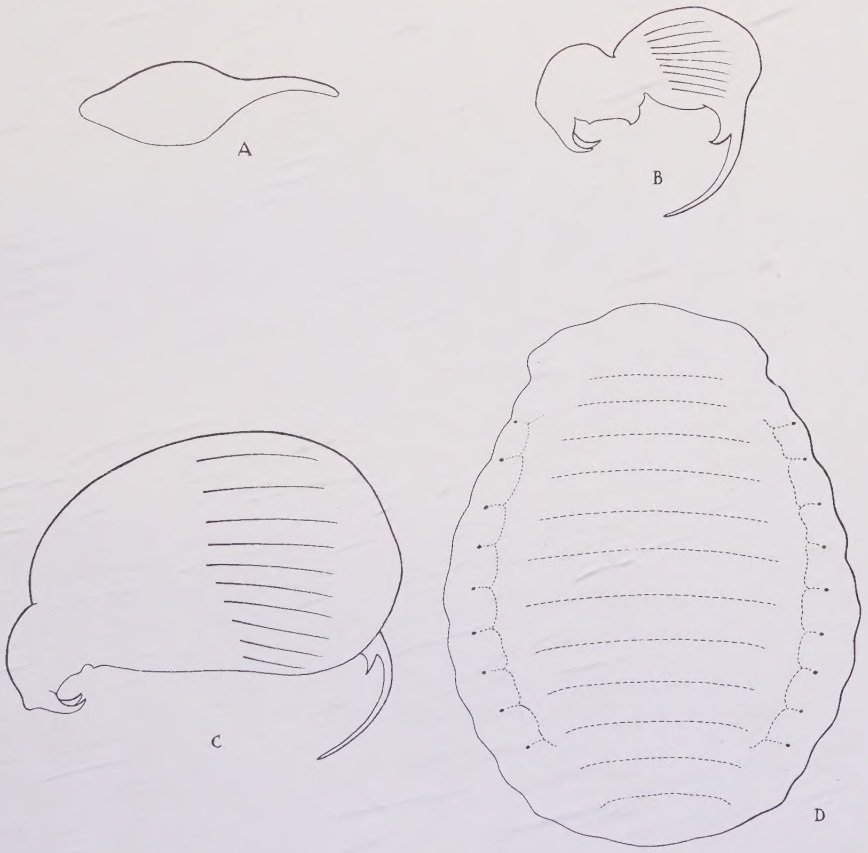


Fig. 2. Stages in the development of *Telenomus nawai* within Spodoptera eggs. Drawings to scale but greatly enlarged. A, newly deposited egg. B, newly hatched larva. C, engorged first stage larva 24 hours after hatching. D, appearance of larva about 36 hours after hatching.

The parasite is thus short-lived; but if moth eggs are available each parasite is capable in the few days of its active adult life of destroying about 50 to 80 of its host eggs and replacing them with an equal number of its own progeny.

The Egg

The freshly deposited egg of the parasite is .13 millimeter long or about one two-hundredths of an inch. It must necessarily be very small since it is placed

within the moth egg, which is only about one-fiftieth of an inch in diameter. It is shown in Fig. 2A. It is rather bullet-shaped with one end drawn out into a curved, blunt stalk. Within 24 hours after deposition it is slightly shorter, more oval in outline and the curved stalk at one end is much shortened and barely recognizable.

The Larva

Moth eggs, opened two days after being exposed to parasites, contain minute, strange-looking, legless, unsegmented larvae. One is shown in Fig. 2B. A tail-like appendage projects forward beneath the body which can be moved backwards and forwards. Elongate bristles, which can be also moved somewhat, extend backwards along the sides and over part of the top of the abdominal region. The head area bears a strong pair of curved mandibular processes. No tracheal or breathing system is discernible. The larva when first hatched is .11 millimeter long. About 24 hours later it has absorbed sufficient liquid food within the moth egg to have become greatly swollen and doubled in length, as shown in Fig. 2C. Otherwise its structure remains unchanged. Shortly thereafter it moults and assumes an entirely different appearance, as shown in Fig. 2D. It now has no distinct head or tail appendage. The body is smoothly oval. A weak constriction separates the head region from the rest of the body. Besides the head, twelve faint body segments can be recognized. A well-defined respiratory system has now developed with nine pairs of distinct lateral spiracles or breathing pores all connected with a tracheal trunk on each side. The larva is now .45 millimeter long. It has almost completely used up the contents of the moth egg and occupies most of its interior.

The larva pupates within the empty egg and from about 12 to 18 days after the parasite egg is first laid a newly matured wasp chews its way out and is soon ready to begin the cycle all over again.

The Adult

The parasite emerges from the moth egg through a ragged exit hole made by biting its way out. Moth eggs from which parasites have emerged are shown in the enlarged photo in Fig. 3, which was made by Mr. Twigg-Smith. Fig. 4 gives in detail the general appearance of the adult female greatly enlarged.

Males nearly always emerge first and remain on the Spodoptera egg mass awaiting the hatching of the females with which they immediately mate.

Females seem to outnumber the males slightly. During March, April and May, 1933, of a total of 2425 parasites hatching from moth eggs collected in the field on Oahu, 1386 were females, or 57.1 per cent.

Life Cycle

The life cycle is very short. Life cycle data were kept in February, 1933, on 93 parasitized Spodoptera egg-masses, comprising a total of several thousand eggs. In all cases the period elapsing from the deposition of the parasite egg to the development and emergence of the adult ranged from 13 to 17 days with most of the emergence occurring in from 13 to 14 days. Life cycle data completed by

Mr. Rosa in March, 1928, on 894 parasites brought identical results. During the hot, summer months the cycle is a few days shorter. Mr. Swezey (6) found that the entire life cycle of the moth occupied from five to six weeks. The cycle of the moth is hence from two and one-half to three times as long as that of the parasite.

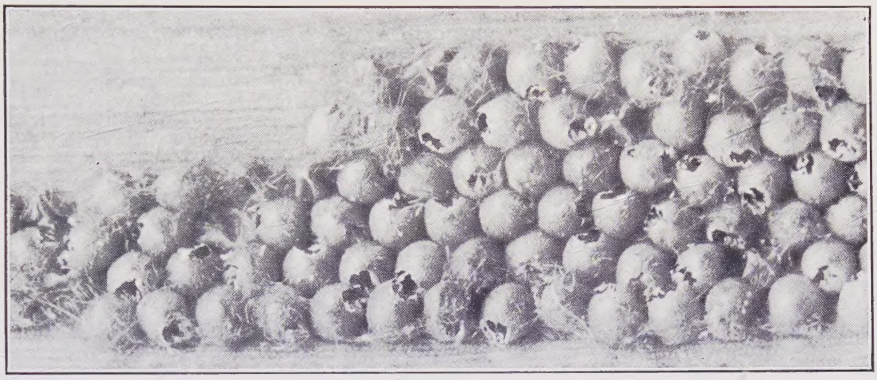


Fig. 3 Eggs of *Spodoptera mauritia* from which parasites have emerged, leaving a ragged exit hole over each empty egg shell. Greatly enlarged.

Fig. 4. *Telenomus nawai*, female, greatly enlarged. (After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields.* 1931.)

Extent of Parasitism in the Field

When Spodoptera egg-masses are found by the parasite, nearly all of the eggs are quickly parasitized. As shown above, under Oviposition, a parasite will usually remain over an egg-mass for an hour or more and lay a large number of eggs once it locates a suitable egg-mass to attack. During May, 1933, 34 Spodoptera egg-masses were collected about Honolulu from cane leaves and at Mapulehu, Molokai, from date palm leaves. These were placed in individual vials to determine the extent of parasitism in each lot. The results give a fair

picture of the value of this parasite. From the 34 lots of egg-masses, 4914 of the eggs produced parasites and only 206 yielded armyworms. This is a parasitism of over 95 per cent. All of the egg-masses but six produced nothing but parasites. Moth eggs deposited on cane leaves and other plants about the Experiment Station grounds in Honolulu and in other parts of the city are usually highly parasitized. However, when the moth flies far afield into cane areas, the minute parasite is slow to follow or may fail to reach regions suddenly invaded by armyworms. The more frequent finding of it within cane fields in recent years is nevertheless encouraging.

During December, 1927, Mr. Rosa collected 38 Spodoptera egg-masses from cane leaves on the Experiment Station grounds and obtained the parasitism record for each lot. Of these, all but five produced nothing but parasites. A total of 5320 parasites and 74 armyworms hatched out. This is a parasitism of over 98 per cent and is again impressive proof of the ability of this parasite to destroy Spodoptera eggs when locating them.

LITERATURE CITED

(1) Proc. Haw. Ent. Soc., 1927, Vol. VI, p. 370.
(2) Proc. Haw. Ent. Soc., 1928, Vol. VII, p. 3.
(3) Ashmead, Wm. H. 1904. Descriptions of new hymenoptera from Japan. I. Jour. N. Y. Ent. Soc., Vol. XII, p. 72.
(4) Gahan, A. B. 1925. Interesting records of two little known parasitic hymenoptera. Proc. Ent. Soc. Wash., Vol. XXVII, p. 188.
(5) Swezey, O. H. 1929. Notes on the egg-parasites of insects in Hawaii. Proc. Haw. Ent. Soc., Vol. VII, p. 284.
(6) ————————. 1909. Armyworms and cutworms on sugar cane in the Hawaiian Islands. Exp. Sta., H. S. P. A., Ent. Bull. 7, p. 15.

How to Measure Effective Temperature in Terms of Day-Degrees

By U. K. Das

The four essentials of crop production are:

(1) Plant food
(2) Moisture
(3) Heat
(4) Light

Of these four, we are accustomed to measure the quantity of plant food that we apply to the soil and the moisture that we receive in rainfall or that we supply by irrigation. We know that in general, our crop yields are markedly influenced by the quantity of both plant food and moisture.

Hereunder, we go a step further and suggest a similarly useful way of measuring the third essential of crop production, namely, heat or temperature.

The temperature as usually measured by thermometers does not tell us how much of it is effective for promoting growth. We know, for instance, that water

freezes at 32° F. and, therefore, there can be no growth at 32° F. It has been found with crops growing in cold countries, like Europe, that vegetation really begins to grow at about 42° F. In that case only temperatures above 42° F. would promote growth. But the fact that sugar cane does not grow very much outside of the tropics would suggest that profitable cane growth cannot take place at temperatures where subtropical crops would thrive. In other words, the heat requirements of cane must be greater. What may be the lowest point at which measurable cane growth will cease has not been experimentally determined. We therefore arrive at a probable value for this minimum point in an indirect manner.

In Louisiana, cane does not generally grow in winter when the mean maximum air temperature is about 63° F. (New Orleans station). Growth starts in early spring in March when the mean maximum temperature is 70° F. Local observations and meager data on hand would indicate that this zero point of cane growth in Hawaii also is in the neighborhood of 70° F.

We therefore assume that measurable cane growth starts at 70° F. of maximum temperature. That this assumed point is not so very far from the truth will be clear when we consider that with a summer temperature of 86° F. and a winter temperature of 78° F., we get nearly two to three times as much growth in summer as in winter. This can only be true if the starting point of cane growth is about 70°. (Very recent studies indicate that this point may be nearer to 73° F. than to 70° F., but until this point is definitely established, we would recommend the use of 70° F. as the zero point.

Accumulated Warmth or Effective Temperature

Effective temperature will then be measured from this base line of 70° F. of maximum temperature. One day having 71° F. of maximum temperature will then be one effective degree for one day or one day-degree.* If we have 30 such days in one month the total effective warmth will be 30 × 1 or 30 day-degrees. If, on the other hand, we have a day with 85° F. of maximum temperature, that day has 85°—70° or 15 day-degrees of heat. If a month in summer, say, August, has a mean maximum temperature of 85° F. (which means that the average maximum temperature of each day is 85° F.), then, the total day-degrees for that month will be the sum of day-degrees in each of the 31 days, or, more conveniently, the day-degrees for an average day multiplied by 31. In this particular instance, this total will be 15 × 31 or 465 day-degrees. Thus, we see that we can add, subtract, multiply or use our temperature in any quantitative manner we want by resolving the temperature records into day-degrees. We can thus compare the sum total of day-degrees in one year with another and in one crop length with another. It is only when we come to evaluating the total warmth received by all the different fields of a plantation started and harvested in different months, that our simple method of summing up day-degrees fails to give us the true picture of the total effective heat received by the total crop. But this difficulty can easily be surmounted by taking into consideration the factors of area and crop length of different fields. Here we can apply the analogy of irrigation water or rainfall. If we give two inches of irrigation to an acre of land,

* Temperature below 70° F. is taken to be of zero value. Thus, days of 60° F., 65° F. or 69° F. all have zero day-degrees.

we say that the water received by the field is 2 acre inches. Two inches over 5 acres would be 10 acre inches and so on. We can do the same with day-degrees. If we have 15 day-degrees of heat received equally by all the fields of our plantation of 3,000 acres, then the total warmth for all the fields would naturally be 15 $\times$ 3,000 acre-day-degrees. Thus, we can calculate for every month the amount of heat received by multiplying the total day-degrees in the month by the area under cane in that month. The acre-day-degrees for each successive month of a crop can thus be added together to give us the total acre-day-degrees received by a particular crop. In Problem III, at the end of this paper, we show how to calculate this sum for a given crop.

In this manner not only can we compare this year's performance with another just as we would compare the efficiency of 200 pounds of N on our plantation this year with 300 pounds N next year, but also we shall be able to compare at any moment the progress to date of the current crop with the same date of the past crop. And this latter evaluation of crop progress to date is bound to be of great help in crop estimations.

Differences in Young and Old Cane

The calculations that we have suggested take no account of the fact that young cane grows faster than old cane and must, therefore, grow more for each day-degree of heat than old cane. Until such time as we have definite information on this difference of growth rate in young and old cane, we would suggest that we disregard this factor and content ourselves with knowing that the proportion of young and old cane in the different years must be approximately the same at any given period. Then, the comparative value of the summated day-degrees will still be good.

Data Must Be Reliable and Representative

Success in using these methods of evaluating warmth must primarily depend on (1) the reliability of the temperature records, (2) the representative character of the data. In other words, does the weather station truly represent conditions all over the plantations or is it of local significance only?

We would, therefore, suggest the use of approved Weather Bureau type of instruments only and we would also suggest that wherever necessary more than one temperature station should be established on the plantation.

Calculations

Problem I. To calculate the total acre-day-degrees for December, 1958.

Area under cultivation=2,000 acres.
Mean maximum temperature for December=80° F.

Therefore, total day-degrees for the month=(80—70)$\times$31=310.*
Total acre-day-degrees=310$\times$2,000=620,000.

* It must be understood, however, that if we have many days in the month with temperatures below the base line of 70° F., then the short cut method of multiplying mean maximum temperature by the number of days in the month will not give us the true number of day-degrees. In such cases, the daily day degrees must be added together.

Problem II. To calculate effective warmth for the summer months, July. August, September, of 1958.

Data=

Area in cane, July =2,000 acres.
August =2,600 acres.
September=3,200 acres.

Temperature mean maximum July =85°.
August =86°.
September=87°.

Day-degree for July =(85—70)×31=465=0.465 thousands of day-degrees.
August =(86—70)×31=496=0.496 thousands of day-degrees.
September=(87—80)×30=510=0.510 thousands of day-degrees.

Thousands of acre-day-degrees for July =0.465×2000= 930.0.
August =0.496×2600=1289.6.
September=0.510×3200=1632.0.

Total for three months = 3,851.6.

Problem III. To calculate the total acre-day-degrees for the crop of 1935 of plantation X, the following table shows the data and the calculations:

A Month	B Area in Cane for 1935 Crop (Acres)	C Mean Max. Temp. for the Months	D Effective Heat for One Day (t°—70°)	Day-degrees for the Month. (No. of Days × Effective Heat)	F Thousands of Day-deg. (Day Degrees÷1000)	G Thousands of Acre-Day-degrees F.×Area	H Accumulated Thousands of Acre Day-deg. to Date
1933							
J	300	78	8	248	0.248	74.4	.....
F	600	79	9	252	0.252	151.2	225.6
M	900	80	10	310	0.310	279.0	504.6
A	1200	81	11	330	0.330	396.0	900.6
M	1500	82	12	372	0.372	558.0	1458.6
J	1800	83	13	390	0.390	802.0	2260.6
J	2100	84	14	434	0.434	911.4	3172.0
A	2400	85	15	465	0.465	1116.0	4288.0
S	2700	84	14	420	0.420	1134.0	5422.0
O	"	83	13	403	0.403	1088.1	6510.1
N	"	82	12	360	0.360	972.0	7482.1
D	"	81	11	341	0.341	921.0	8403.1
1934							
J	"	79	9	279	0.279	753.3	9156.4
F	"	80	10	280	etc.	756.0	9912.4
M	"	81	11	341		920.7	10833.1
A	"	82	12	360		972.0	11805.1
M	"	83	13	403		1088.1	12893.2
J	"	84	14	420		1134.0	14027.0
J	"	85	15	465		1255.5	15282.7
A	"	86	16	496		1339.2	16621.9
S	"	85	15	450		1215.0	17836.9
O	"	84	14	434		1171.8	19008.7
N	"	83	13	390		1053.0	20061.7
D	"	82	12	372		1004.4	21066.1
1935							
J	"	77	7	217		785.9	21852.0
F	2400	78	8	224		537.6	22389.6
M	2100	79	9	279		585.9	22975.5
A	1800	80	10	300		540.0	23515.5
M	1500	81	11	401		601.5	24117.0
J	1200	82	12	360		432.0	24549.0
J	900	83	13	403		362.7	24911.7
A	600	84	14	434		260.4	25172.1
S	300	85	15	450		135.0	25307.1
		Total.....				25307.1	

NOTE—All data are imaginary. Assumed nine months of harvest from January to September.

Use of Day-Degree to Compare One Area With Another

The day-degree may also be advantageously used to compare the performance of one field or area with another. In that case we can measure the yields of the two areas in terms of "yield per acre per 1,000 day-degrees." Thus, we may find that there is no difference between a mauka and makai land yielding, say, 5 and 7 tons, respectively, of sugar when we reduce this yield to the basis of 1,000 day-degrees.

A Basic Fertilizer Plan and Schedule

By R. J. Borden

With the premise that it is necessary for us to use commercial nitrogen, phosphoric acid, and potash fertilizers, if we are to continuously produce economical crops of sugar cane, we are immediately concerned with a plan that will make use of these nutrients in a way that will be reflected in enhanced profits. With a further premise that any one of these nutrients may be safely omitted from a fertilizer practice only when we have evidence that the natural supply within the root zone will be sufficient for the immediate crop, and that supplementary additions to a satisfied soil would only result in an intensified absorption without an increase in yield, we are then interested in finding such evidence. Fortunately, the chemist, the plant physiologist, and the agriculturist have cooperated to give us guides to intelligent fertilization that are extremely useful, though not always infallible, and as we make wider use of such guides and become more adept in interpreting their results, our use of fertilizers will become more efficient and profitable.

Amount to Apply

Without evidence to the contrary, a conservative fertilizer practice that recognizes the necessity for preserving the soil as well as for providing the necessary chemical foods for the cane plant to convert into sugar, might well be built out in two directions from a base line that would supply each crop with 200 pounds each of nitrogen, phosphoric acid, and potash. Departures from this base line would be made as evidence became available to indicate that more or less of any one nutrient was desirable. Such a basic fertilizer, at present prices for commercial materials, should not cost much over $35 per acre applied in the field, ($15 for nitrogen, and $10 each for phosphate and potash), and hence appears a very reasonable expenditure for the increased sugar yield it is capable of making. With such information as the expected cane tonnage, the results of chemical analyses of soils, soil solutions and leachates, and of the cane plant tissues and juices, and of the by-products of manufactured sugar, as well as the results from Aspergillus and from Mitscherlich tests with indicator crops, and of the field experiments with sugar cane itself, we have guides for deviating from this basic plan that will help us to increase its efficiency or to decrease its cost. Hence the

following plan is offered, with the suggestion that all quantitative data therein be considered not as absolute amounts but as rough estimates of trends or directions for guidance.

A BASIC FERTILIZER PLAN

With Guides for Deviating From Same

Lbs. to be applied	N	P_2O_5	K_2O
0		No response to P_2O_5 in field tests. Cit. sol. at .008% +. .04% + in juice. Mitsch. at 250 lbs. +.	No response to K_2O in field tests. Cit. sol. at .04% +. Mitsch. at 750 lbs. +. Molasses at 5.0%.
100		Cit. sol. at .004% +. .03% + in juice. Mitsch. at 150 lbs. +.	Cit. sol. at .03% +. Mitsch. at 550 lbs. +.
150	For 40-50 tons		
200	BASIC SCHEDULE For 60-70 Tons Cane		
250	For 80-90 tons Long crops		
300	For 100 tons Long crops	.01% in juice. Phosphates added to juices at the mill.	Cit. sol. at .01% —. Mitsch. at 250 lbs. —.

The Citric Soluble and Mitscherlich analyses are to be made on soil samples collected immediately after the harvest of the crop upon which juice analyses were made, and the information thus obtained is to be used as a guide for fertilizing the succeeding crop.

The amounts suggested in this roughly devised basic fertilizer plan have been conceived as sufficient for the average 60- to 70-ton cane crop. For lesser tonnages, the suggested amounts may be decreased from the 200-200-200 base line, although it is doubtful whether the nitrogen figure should be planned at much less than 125 to 150 pounds. For greater tonnages, increases over the base application, particularly of nitrogen, are in order.

As regards phosphoric acid: If it is a practice to add phosphates at the mill in order to settle the cane juices, or if an analysis of the crusher juice shows a P_2O_5 content of less than .01 per cent, we have a fairly sure indication that the soil phosphate supply is pretty low and that a somewhat heavier crop fertilization with phosphate is called for. On the other hand, if a fairly good agreement exists on the other (upper) side of our base line for P_2O_5, between the figures that indicate a medium to high supply of this nutrient in the soil and in the plant, we may well consider decreasing the amount to be applied. In a case where the guides *all* point to a large available supply of phosphates, we believe that we can safely omit this material from the fertilizer practice. Whenever such a decision is made, however, it will be wise to install a good field experiment that will afford

a check on a series of yields of paired plots with and without phosphate. Such an experiment should be continued as long as our decision to withhold phosphate fertilizer is effective, so that we may catch a trend in the experiment before it becomes operative in the field.

With citric soluble K_2O in a soil at less than .01 per cent, or with a Mitscherlich figure indicating less than 250 pounds available to Sudan grass, we feel that an increase in potash over the basic application is warranted. Where, however, the evidence quite clearly points to an ample supply for the crop, we believe that a considerable cost saving can be made by decreasing or by even eliminating potash from the crop fertilizer program. Such a decision as the latter would concurrently be checked by field experiments in order to watch the trends that might follow such a procedure if continued for many years.

In using these suggested guides for deviating from the basic plan, one must be cautioned not to make decisions on the basis of any single guide alone. We have offered several and in time we should be able to offer still more. In the meantime, if there is a lack of agreement between the suggested guides in the same group, the wisest policy will be (1) to make sure that we are providing the cane plant with sufficient raw material to make the expected crop, and (2) to resample the field in question, since this lack of agreement may be due to inadequate or to non-representative sampling. Two hundred pounds of phosphate or of potash can be applied for about $10.00 per acre and unless we know quite definitely that the available soil supply is fully adequate, we cannot afford *not* to make this expenditure.

Time to Apply

After having decided on the amounts of nitrogen, phosphoric acid, and potash that we shall apply, we are later confronted with the problem of when these materials should be applied for greatest efficiency. We have many opinions, but little data to answer this question, but we believe that we have a good indication that is given to us by the cane plant itself.

With the use of soluble fertilizer salts which are readily available to the cane following their application to the soil, it would seem reasonable to try to supply the more elusive elements when and as needed by the plant. Thus the time and amount of absorption, particularly of N and K_2O by a healthy, well-nourished cane crop should offer a good guide to the time of application of these nutrients.

In the accompanying graphs there is presented a picture of the maximum amounts of N, P_2O_5, and K_2O that were found in an acre of cane (including roots, stalks, and leaves) at its various stages of growth. The data from which these graphs were drawn have been presented before* and the information is offered again as the best evidence we have for use in guiding our time of applying fertilizer. The two smaller graphs are interpolations from the larger graph to show the more rapid absorption of nutrients during the "boom stage" as contrasted with the slower but continued absorption during the same calendar months of the second year's growth. This is particularly true of potash and nitrogen.

* By G. R. Stewart at the 1929 meeting, and by W. W. G. Moir at the 1930 meeting of the Association of Hawaiian Sugar Technologists.

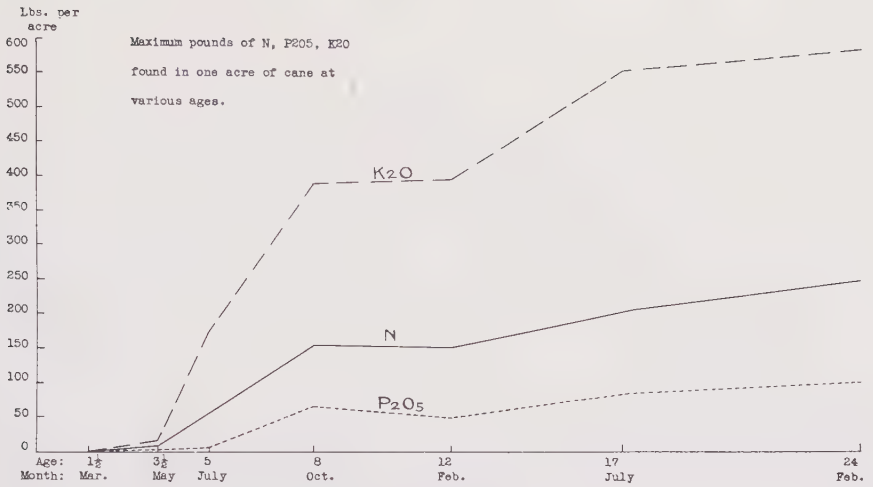

Lbs. per acre
Maximum pounds of N, P205, K20 found in one acre of cane at various ages.
600
550
500
450
400
350
300
250
200
150
100
50
0
K2O
N
P2O5
Age: 1½ 3½ 5 8 12 17 24
Month: Mar. May July Oct. Feb. July Feb.

Fig. 1

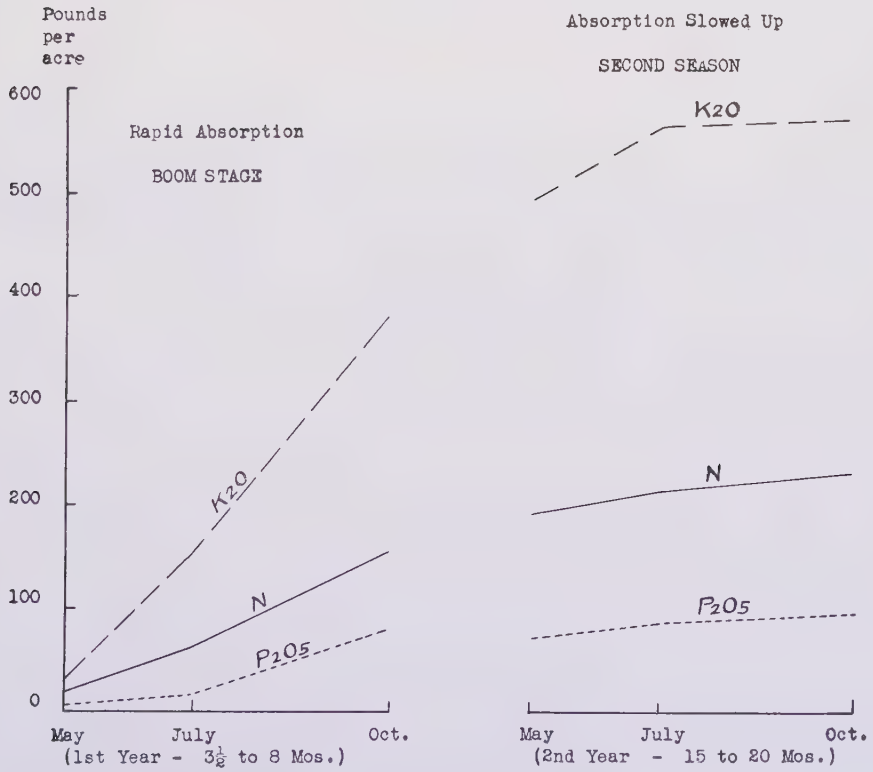

Pounds per acre
600
500
400
300
200
100
0
Rapid Absorption
BOOM STAGE
K20
N
P205
May July Oct.
(1st Year - 3½ to 8 Mos.)
Absorption Slowed Up
SECOND SEASON
K20
N
P2O5
May July Oct.
(2nd Year - 15 to 20 Mos.)

Fig. 2

An inspection of these graphs will show the following:

(1) Less than 10 per cent of the total N, P_2O_5, or K_2O which the cane finally had taken up at 24 months, was in the plant at the age of 3½ months.

(2) Less than 30 per cent of the total N, P_2O_5, or K_2O absorbed, had been taken up by the cane plant at 5 months.

(3) Only approximately 60 per cent of the total nutrients had been absorbed by the end of the twelfth month, and most of this absorption took place at from 3 to 9 months.

Considering the general nature and characteristics of our cane soils, and with these nutrient absorption data in front of us, we should like to offer the following schedule for applying the amounts of N, P_2O_5, and K_2O as indicated in our basic fertilizer:

(1) Not more than 10 per cent of the total nitrogen before the sixth week, with 20 to 30 per cent at 3 months, 30 to 40 per cent at 5 months, and the remainder after the eighth month, applied alongside the cane row.

(2) All the phosphate in a single application within the root zone as soon as the crop is started.

(3) Potash in a split application when the total amount is to be over 150 pounds per acre, preferably at about 3 and 5 months, applied alongside the cane row with the nitrogen.

Undoubtedly there will be many reasons for deviating from such a schedule as offered, and these will need to be considered in the light of their greater possible resultant values from the use of fertilizers to make profits from sugar production. Perhaps at some later date, such reasons will be evaluated and set down to guide us in making similar deviations from this basic schedule for time of application as we have already suggested for our basic amounts to apply.

Phosphate Fixation in Hawaiian Soils

By Francis E. Hance

The staff have devoted attention for some time to the study of the fixation of phosphates in Hawaiian soils.

The present paper is offered as a resumé of the developments brought about as a result of Experiment Station research.

An endeavor has been made to present the subject in terms of simplicity and to avoid the usual technical phraseology.

The term "fixation" in its general sense is defined as "the process of rendering permanent."

For our purposes phosphate fixation refers to the retention in the soil of applied soluble phosphate fertilizers by a process of absorption or chemical precipitation, or both. The process is not necessarily permanent. We believe it subject to correction, more or less.

Phosphates once fixed, however, may be held so tenaciously by the soil that root systems of plants can utilize or absorb but very small amounts. The requirements of the growing plant for phosphates are not uncommonly in excess of the supply

which the root systems may contact and absorb. Even a large application of a soluble phosphate such as ammophos or superphosphate may become locked up in the soil to such an extent that the plant may not be able to extract this applied phosphate fast enough to satisfy its needs. We say, then, that in such a case the application of phosphate fertilizer has been so tightly "fixed" as to seriously diminish the amount available to the plant.

In the investigation of phosphate fixation in any given soil it is necessary, of course, to add a quantity of known phosphate to that soil so that fixation may take place. If it were easy to remove all the phosphate which had been so applied and which had not become fixed, then it follows that analyses of the soil before and after fixation would show an increase in the amount of phosphate present. This amount would, of course, be equal to the quantity fixed. However, the method is very cumbersome. It is easier and equally as proper to analyze a solution before its application to the soil and again after it has passed through it under controlled circumstances. Then the decrease in the amount of phosphate in the solution can be used to calculate the amount of phosphate which has become fixed.

A soil extraction with a solution of phosphate is used with the Experiment Station phosphate fixation kit; likewise in employing the method of Demolon and Barbier and in other laboratory experimental work.

Results obtained by use of the phosphate fixation kit depend upon extraction of a soil with a neutral solution containing a definite concentration of phosphate. The soil is shaken with the solution and allowed to stand long enough for fixation to occur. Then the liquid is filtered off and certain chemicals are added to it which produce a blue color, the intensity of which is directly proportional to the phosphate remaining in solution. The lighter the color the less phosphate which has been fixed by the soil. Conversely, the darker the blue produced (within limits of the test) the more phosphate which is carried by the solution and hence not removed or fixed by the soil. The test serves as a means of ascertaining the relative fixing powers of various soils in a general way, and it can be used quickly and easily in the field or plantation laboratory.

It often happens that a particular strength of phosphate solution may produce in two soils the same apparent degree of fixation when measured by the standards of the fixation kit or by other simple methods. Hence, in evaluating such soils in respect to fixation characteristics, one may safely class them in the same general category. However, in a more detailed study of these two soils it may develop that any one or more of several strengths of phosphate solutions (differeing from the one referred to above) may react so differently when percolated in these soils that the similarity first generally indicated may be found actually as not as marked. For extensive researches it is accordingly advisable to extract a soil with a series of solutions containing different concentrations of phosphate. A more nearly complete understanding of the characteristics of a soil may be obtained in this manner.

We may digress a moment to suggest a field analogy. Consider the situation in the soil following an application by hand in the line of, say, 250 pounds per acre of P_2O_5 as ammophos. Let this be followed by a number of successive rains or irrigation. The first downward movement of water through this ammophos would carry a high concentration of the fertilizer. As the concentrated solution seeps

through the soil the latter may extract or fix a greater part of the phosphate which the solution carries. The actual zone of phosphate movement may not exceed 2 or 3 inches. Should this soil have very high "fixing" ability, the phosphate already fixed may be added to by additional phosphate dissolved in subsequent irrigation movements and, after an entire agricultural season, one may find that the maximum penetration of applied phosphate did not reach a level five inches below the surface. In another type of soil having mild "fixing" characteristics, the same amount of applied soluble fertilizer may reach the second or even third foot profile level. In most Hawaiian soils, however, fixation of applied soluble phosphates appears to occur over a variable period of time, well within the normal root zone areas and yet ultimately so completely that little or no loss of this nutrient is occasioned by seepage or leaching.

Relevant to methods of studying soils in reference to phosphate availability and soil phosphate fixation: We have seen that it is necessary to extract a soil with solutions of various reagents (including phosphate) in order to determine its probable behavior or reaction to fertilization in the field. A practice almost universally followed is to lightly acidify all solutions intended for laboratory soil extraction studies. Hence, in the evaluation of a soil for ascertaining its concentration of "available" or readily soluble nutrients an extraction is usually made with a dilute organic acid such as citric acid or a very dilute inorganic acid such as nitric acid or sulfuric acid. The acid extraction, within limitations, is designed to parallel the nutrient extracting ability of the plant roots. It has been found necessary in soil-phosphate fixation studies to employ dilute acid extractions together with solutions of phosphate-bearing salts. Related research requires soil and solution manipulations in which no acids are employed and in which field conditions pertaining to soil-fertilizer and irrigation are more nearly approximated. Regulated concentrations of phosphates in solution, however, are employed in all fixation studies.

Hence, in the method of Demolon and Barbier and in other researches in the laboratory, a series of extractions have been made using variable concentrations of phosphate in the process.

Demolon and Barbier, in their studies with French soils, used acetic acid extraction solutions containing variable amounts of phosphate. From the data certain calculations were made which enabled them to estimate the requirements of their soils.

Recently, Davis and Ayres have been using phosphate solutions containing no acids. This procedure has certain distinct advantages:

(1) The pH of the mixture is very nearly that present in a soil when phosphate fertilizers are added instead of being distinctly acid. Thus the results should more closely approximate what happens in the field.

(2) An acid dissolves an amount of the phosphate originally present in the soil at the time the sample is collected. This, added to the amount present in the solution constitutes the *true initial concentration* of the solution, part of which becomes fixed. But we do not know how much phosphate was dissolved since it does not all remain dissolved, but becomes partly fixed. With neutral solutions which do not dissolve phosphate appreciably in most cases, we know exactly how much has been added and how much remains soluble, and, therefore, how much has become fixed.

(3) Acid solutions change the characteristics of a soil very markedly and therefore introduce an additional complication.

(4) The analytical determination of phosphate in a neutral extract is much more simple and accurate than in an acid extract which contains iron and other interfering substances.

In making quantitative analytical studies of soil phosphate fixation the investigator must give full consideration to the mechanism of fixation as it occurs in the field.

It has been determined that phosphates do not become "fixed" by gravel or sand. It has also been established that phosphate must be soluble in water to become "fixed." It is also true that the presence of colloidal matter in a soil is one factor which appears to markedly enhance fixation. It is believed that the greater the percentage of colloidal matter a soil may carry, just so much greater may be the amount of fixation—all other conditions being equal.

"Colloid," "colloidal," or "colloidal state" will be referred to from time to time. A few explanatory remarks regarding colloids may be appropriate. To be colloidal, substances must exist in extremely fine division. Fineness of division is imperative to the rendering of a substance capable of becoming colloidal. Smoke, for instance, is a colloidal suspension in the atmosphere of the solid residues remaining after imperfect combustion of organic substances. However, this solid material exists in a state of ultra microscopically fine division. The common lamp black pigment of commerce is obtained by bringing a moving cold surface in contact with the combustion products of imperfectly burned petroleum oil. Carbon in ultimately fine division, and hence colloidal, is deposited on the cold surface. Similarly, mist is a colloidal suspension of minute particles of water in air. A popular floating soap derives its floating properties entirely from mechanically introduced air distributed throughout the mass of the product in microscopic globules. In this case, air is colloidally suspended in the soap. Milady's facial cream carries a colloidal suspension of rose water in lanolin (oil) and bleached bee's wax, the "cream" being stabilized by a small amount of borax dissolved in the rose water. Mayonnaise dressing consists essentially of a colloidal suspension of lemon juice or vinegar intimately distributed in olive oil through the agency of agitation and rendered permanent by additions of egg albumen. Milk is a temporary suspension of butter fat in a watery whey aided by casein, the latter compound constituting one of the common commercial glues.

Clear red ruby glass—that used in photography and in railroad signal systems —owes its rich red color entirely to an extremely fine suspension of metallic gold in the glass. Were a large sheet of this glass to be remelted the gold could be recovered unaltered in a fine powder capable of being fused into a nugget. The metallic gold in this glass is present in a state of colloidal suspension.

Any soil containing appreciable amounts of finely divided clay will, when shaken with water and allowed to stand, become separated into fractions of granular particles and colloidal soil matter. The granular portion will settle out quickly to the bottom of the container. The colloidal portion will come down at a much slower rate, but in the interim the water above the settlings will remain dense and murky with suspended colloidal soil. Eventually two distinct layers (usually of different

color) may be observed in the bottom of the container. The lower layer will consist of distinct particles, readily distinguished by the eye. The upper layer will carry finely divided soil particles, many of which will be so minute that even a high-powered microscope would fail to enlarge the image sufficiently for detection.

We have seen that in the state of fine division solid, insoluble substances may readily be rendered colloidal in water, oil, air or other vehicles. Finely divided soil particles naturally assume the cololidal state in most of our lands.

But few question the finding that soil colloids are an important contributing factor in the fixation of applied soluble phosphates. One having access to an Experiment Station fixation kit may demonstrate to his own satisfaction the truth of this statement. Following the simple directions for making the tests he might compare a black sand or undecomposed lava ash with a heavy, rich colloidal soil from any source within the Islands. Without the colloids and provided no substances are present in the sample which may precipitate phosphates, he will find scant fixation. On the other hand, a highly colloidal soil may "fix" a great part or even practically all of the phosphate with which it may be brought in contact in making the test.

Since the colloidal state requires the presence of finely subdivided material, the size of soil particles is of significance in phosphate fixation. It is probably true that the percentage of finely divided soil has some bearing upon the rate of fixation. Some rather startling facts have been observed by Ward in connection with his studies of particle size distribution in Hawaiian soils. In many of them 50 to 60 per cent by weight of the soil is composed of fine particles having diameters less than one twenty-five-thousandth of an inch. More than 90 per cent of the total surface area of some of our soils is derived from particles of this size or smaller. In a consideration of these findings from the viewpoint of the tremendous surface areas of the soils involved it may be stated that there are more than one thousand square miles of particle surface existing in an acre-foot of such a soil. Since the phenomenon of fixation seems so intimately related to this matter of soil colloids and soil particle size it is believed that the relative magnitude of surface areas in various soils may prove of considerable importance in correlating and classifying soil types on a basis of their propensity to fix phosphates.

It has been shown that the fixation of applied soluble phosphates may occur within the colloidal fraction of a soil. It is also necessary to consider chemical reactions taking place in the soil which may result in the precipitation of applied soluble phosphates in the form of insoluble compounds. The precipitation may be brought about by reactions of the fertilizer with calcium salts, hydrated compounds of iron, compounds of aluminum, or other constituents normally present in the soil. Granted that such precipitations do occur; then it would be in order to learn if the roots of a plant could feed upon or utilize such precipitated compounds of phosphorus. Another investigator in Hawaii, in studying mainland soils, has been successful in synthesizing a compound of hydrated iron with phosphate which is extremely insoluble and which appears to be very similar in chemical and physical properties to the difficultly soluble phosphates formed in the soils after the application of a readily soluble fertilizer phosphate. This same investigator found that his synthesized insoluble phosphate was quite similar to a natural soil mineral known as dufrenite ($Fe_2[OH]_3PO_4$).

Surface Feeding

Greenhouse pot experiments designed by R. R. Ward and P. L. Gow are now in progress from which it is hoped to obtain information relevant to the ability of the cane plant to obtain its required phosphate from insoluble compounds. We had reason to believe that certain insoluble phosphates, such as raw rock and reverted phosphate, when applied to the soil would eventually become available for the use of the plant.

It has been suggested that fixation may occur in the soil by the formation of iron or aluminum phosphates following the application of a soluble phosphatic compound. Reiterating that only phosphates which are in solution in the soil water can be fixed, then, those forms of applied phosphate which do *not* dissolve in the soil solution *cannot* be fixed. But, if such compounds are not fixed and yet remain in the vicinity of the roots, can the plant feed upon them? If so, which of the insoluble phosphates are most available to cane? To answer these questions a silica sand culture experiment has been installed, using a number of different kinds of insoluble phosphates.

The treatments, at the rate of 300 pounds of phosphoric acid per acre, are described by Ward as follows:

1. Freshly precipitated tricalcium phosphate (phosphate of lime).
2. Freshly precipitated ferric phosphate (phosphate of iron).
3. Freshly precipitated aluminum phosphate.
4. Raw rock phosphate.
5. Reverted phosphate.
6. Superphosphate treated with sodium silicate and washed to remove soluble phosphate.
7. Raw rock phosphate treated with sodium silicate and washed to remove soluble phosphate.
8. Control; no phosphate.
9. Control; soluble sodium phosphate added in culture solution.

The materials were all thoroughly washed to remove any soluble phosphate which might have been present. (It should be noted that freshly precipitated tricalcium phosphate is very different, chemically and physically, from raw rock phosphate.)

All the pots are receiving complete culture solution minus phosphate, except those of Series 9, which, in addition, are receiving soluble phosphate as shown above.

Pure silica sand was used in the pots rather than soil in order to avoid the effect of any changes in solubility of the phosphates which might be caused by the soil. For the same reason, the culture solutions are applied by a constant drip method rather than intermittently in order to prevent the development of acidity in the unbuffered sand; to be more certain of this condition, a pound of commercial ground coral rock was added to each pot.

Five replications of D 1135 cane are being used for each of the treatments and are considered sufficient to show which of the insoluble phosphates being studied are most readily available to this variety, and how this availability compares with that of soluble sodium phosphate.

The plants used for the experiment are lalas which were cut from a field whose last fertilization was made more than a year and a half previous to the collection. After planting in flats containing silica sand the lalas were placed in a very fine spray of water to reduce transpiration until strong root systems were developed. At this time the plants were transferred to the experimental pots.

On June 8, 1933, some six months after planting, marked differences appeared in the response of the plants to the various treatments. The reverted phosphate series was far in the lead of any other of the insoluble forms. Response in this case was even slightly better than that shown by the plants receiving soluble sodium phosphate. Measurements were taken of the maximum height of each plant and the diameter of the largest stalk; the number of shoots on each stool was also counted. When each of the factors received equal weight in grading, and the reverted phosphate treatments were given an arbitrary score of 100, the various treatments were classified by Ward as follows:

Reverted phosphate	100.0
Sodium phosphate solution	96.5
Freshly precipitated aluminum phosphate	76.3
Freshly precipitated ferric phosphate	61.2
Superphosphate plus sodium silicate	70.4
Freshly precipitated tricalcium phosphate	66.7
Raw rock phosphate plus sodium silicate	57.0
No phosphate	54.3
Raw rock phosphate	50.3

At the present time, October 12, 1933, the experiment is showing interesting developments. We believe it has been definitely established that D 1135 cane can utilize tricalcium, ferric, aluminum and reverted phosphates. In fact, the ferric, aluminum and reverted phosphate series show more stalk development and more millable cane than do those receiving soluble phosphate in the culture solution, although the latter show on an average a larger number of stalks per pot. A detailed discussion of the various treatments in the order of their responses at the present time is quoted below from a report by Gow, dated October 12, 1933:

Ferric Phosphate: This treatment, while it always showed good response, was outstripped by reverted phosphate, sodium phosphate and aluminum phosphate until the early part of July, when it began to show unusually rapid growth. During the first month of the experiment some of these plants showed rather definite evidence of plugging of the vascular bundles with iron. This was quickly cleared up by increasing the amount of potash in the culture solution, but it may explain why the ferric phosphate treatment tended to lag behind some of the other treatments during the early months of the experiment. At present this treatment is outstanding from the standpoint of size of stalks and total amount of millable cane.

Aluminum Phosphate: This treatment is somewhat poorer than the ferric phosphate series and is little, if any, better than the reverted phosphate. Like the ferric phosphate plants, they showed considerable evidence of plugging due to deposition of aluminum salts—a condition which was quickly cleared up by increased potash. These plants have also pulled ahead of other treatments in the past two months.

Reverted Phosphate: At the end of the first month this treatment was much the best of all and continued to hold this place during the second, third and fourth months. However,

during the fifth month the development of these plants in relation to other treatments showed a tendency to slow up somewhat. At present they are still making good growth, although the young suckers show an inclination to die off within a week or two after sprouting. This tendency may disappear after the end of the hot weather, as the death of these suckers seems to be correlated with periods of especially high temperatures in the greenhouse. Reverted phosphate is still one of the best treatments and bids fair to maintain this place.

Sodium Phosphate Solution: While showing very good growth and a marked tendency to stool out, this treatment does not show at present the remarkable stalk development to be observed in the case of the preceding three treatments. Since the second month these plants have all showed unmistakable symptoms of iron deficiency, a disorder which we have been unable to entirely correct. Attempts at alleviation have been made by applying ferric citrate, ferric tartrate, ferrous tartrate, ferrous sulfate, ferric lactate and colloidal ferric hydroxide, and while examination of the sand in these pots shows an excess of iron in an available form, these particular plants appear to be unable to take up enough iron for their needs. The symptoms do not appear to be serious, consisting as they do of somewhat chlorotic stripes along the leaves, and there is no evidence of acute suffering for lack of iron. It is quite possible, however, that this inability to absorb sufficient iron may account for the failure of these plants to show up better than the four preceding treatments.

Tricalcium Phosphate: Of the five replications comprising this treatment, two are mediocre, two are fairly good and one is the best plant in the experiment. There is no doubt that this form of phosphate is at least somewhat available since none of the plants are showing signs of acute phosphate deficiency, but the ability to utilize this form of phosphate appears to depend somewhat on the individual plant.

Superphosphate plus Sodium Silicate: This treatment has shown a marked gain in the past two months, both in the matter of stalk growth and of development of new stalks. We feel that it is too early to form a definite opinion concerning it, but it appears to offer a good deal of promise.

Raw Rock plus Sodium Silicate: This treatment is definitely better than raw rock alone and bids fair to continue improvement at a greater rate than the raw rock. This result cannot be due to the presence of sodium silicate in the pots since it was carefully washed out after treating the raw rock previous to adding the fertilizer to the pots. It should also be noted that sufficient silica for the needs of the plants is being supplied in the culture solution. The most satisfactory explanation of the superiority of these pots over those containing raw rock alone seems to be that the sodium silicate has some chemical effect on the raw rock phosphate which renders it more available for plant assimilation.

Raw Rock Phosphate: Measurements taken June 8 showed the raw rock treatment to be somewhat poorer than the no phosphate treatment, indicating the possibility of a mildly toxic effect of the raw rock. However, at present the raw rock pots are showing definite response and are markedly better than the no phosphate pots. It is interesting to note that this improvement did not become noticeable until the beginning of the sixth month and that during this month it has been so rapid. It is unfortunate that the plants are now becoming so root-bound that the experiment will have to be discontinued at the end of October. This "delayed availability" of raw rock merits further study.

No Phosphate: These plants are all slowly dying. They continue to put out new leaves at a very slow rate, but the stalks are becoming progressively smaller, and in many cases the joint between leaf sheath and blade is lower on the newer leaves than on the older ones. The leaves are extremely narrow and of the somewhat grayish tinge that appears to be characteristic of phosphate deficiency.

Since it is important to the validity of this study that the pH of the pots be kept neutral or slightly alkaline in order that the insoluble phosphates remain insoluble, Gow recovered samples of the solution as it dripped from the bottom of the various pots to determine if there were any noticeable variation in pH as the solution percolated through the sand about the roots of the plants. The remark-

able result of these determinations was to show that, while the solution going into the pots had a pH of exactly 7.0, the solution leaving them gave a reaction of 7.8. Moreover, this finding was independent of the treatment and of the rate of percolation, all of the pots in the experiment yielding solutions of approximately the same pH. This increase in alkalinity cannot be attributed to the calcium carbonate which was mixed with the sand as the pH of the original culture solution was regulated by keeping the solution in contact with calcium carbonate for 24 hours. Therefore, it must be attributed to the effect of the plant roots upon the solution as it flowed around them. This effect is of interest and merits further study.

On the whole, the results to date have been extremely satisfactory and we feel safe in stating that the primary purpose of the experiment has been accomplished. Our efforts were directed to learning the answer to the question: Which water insoluble forms of phosphate are available to cane plants under conditions of pH which will insure continued insolubility?

From a practical viewpoint, the behavior of reverted and raw rock phosphate point to the possibility of using a combination of these two fertilizers to by-pass fixation. Gow suggests that the reverted form should supply the needs of the young cane during the first 6 or 8 months and the raw rock may well carry on from this point. Further study may be necessary to determine how these materials must be handled when the further complication of the soil environment is added to the system; but the results of this experiment indicate the chemical principles upon the basis of which fixation of phosphates may be averted.

Effect of Molasses and Silica Upon Fixation

Ayres has studied the effect of several treatments upon the phosphate fixing characteristics of soils. Two substances covered in his studies, namely, molasses and soluble silica, were found to effectively reduce fixation. The duration of this influence has not as yet been determined. While applications of soluble silicates are pronounced in effecting a reduction of phosphate fixation, silica does not appear to compare favorably upon an economic basis with equivalent quantities of soluble phosphates.

Ward, too, has found that the addition of silica acid to soils greatly reduces their fixing power for phosphates.

His research supported findings of other investigators who have shown that the ratio of silica to iron and aluminum in the soil colloids furnishes a measure of the acid or base absorbing power of the colloids. If this ratio is high, bases are fixed to a large extent and if it is low, acids such as phosphoric are more strongly fixed. The ratio of silica to iron and aluminum is extremely low in Hawaiian soils, and, as a consequence they should fix phosphate to a large extent. Such we know to be the case. If the ratio could be increased, the fixing power for phosphate should be decreased.

It was with this idea in mind that soils were experimentally treated with silicic acid. Ward's laboratory studies showed that the amounts of phosphates fixed by the treated soil were very much less than quantities fixed by the original soil.

We have learned that even extremely large applications of phosphoric acid, in the form of soluble phosphates, to our high fixing soils will result in from 95 per

cent to nearly complete fixation within a matter of weeks. During this interval an equilibrium tends to become established between the very small percentage of soluble phosphates remaining in the soil solution and that which has become fixed within the soil complex. The ratio of fixed phosphates to soluble phosphates may be different, and probably is different for all distinct soil types. Soils may be distinguished very readily by directing attention to the relative amounts of phosphate which are not fixed. As a specific example Ayres, in comparing the fixing ability of a number of soils, found that when phosphate was added at the high rate of 5,000 pounds per acre-foot the fixation, at the end of five days, ranged from 98.33 per cent to 99.95 per cent. But, while these values appear to be of the same order of magnitude it will be noted that thirty-three times as much P_2O_5 remains unfixed in one soil, the lowest fixing specimen, as compared with the highest fixing soil. This fractional residue of unfixed phosphate is vitally important in supplying the plant with available nutrients.

In the laboratory, Davis has been able to leach out a portion of the small amount of the soluble phosphate remaining in the soil solution after a soil has been treated with a phosphate, and fixation has occurred. In doing so, however, he found that a portion of the fixed phosphate becomes disengaged from the soil complex and eventually reappears in the soil solution. Forces are thus operating in the soil which tend to restore an equilibrium between the phosphate remaining fixed and that which is dissolved in the soil solution. As a result of leaching by the passage downward through the soil of rain or irrigation water this equilibrium becomes disturbed by the removal of a certain amount of the phosphate in solution. Then reactions in the soil tend to reestablish that equilibrium as already mentioned. If this be true, it follows that were the cane plant to remove phosphate from the soil solution instead of its having been washed by leaching, the equilibrium should in time be reestablished. The fixed phosphates then would function to a variable extent as a supply for the use of the plant. While it is probably true that such reactions do occur in the soil, it is also quite obvious that some excessively high fixing soils do not allow the readjustment of equilibrium reactions to take place fast enough to supply the needs of the growing plant. In such a case we do have phosphate starvation in spite of heavy applications of soluble phosphates because the amount of phosphate which remains soluble is very small and likewise because of the slow rate at which the fixed phosphates may be given up by the soil complex to the soil solution. The staff of the department are at present devoting attention to this study.

The Rate of Phosphate Fixation

We may also distinguish one fixing type of soil from another by studies of the rate at which applied phosphates may be fixed. In a Manoa soil of very high fixing power Davis found that when treatment consisted of a very large application of phosphate 80 per cent was fixed in twenty-four hours in a laboratory experiment involving constant agitation. Ninety per cent had been fixed at the end of 4 days, 95 per cent at the end of 8 days and 96 per cent at the end of 15 days. After a period of six weeks, fixation was still increasing, but very slowly. Davis suggests, however, that in the field the rate undoubtedly would be very much slower and would depend upon a number of related factors.

In a cooperative study with J. N. P. Webster, Ayres made a number of soil extractions from specimens obtained four months after experimental treatment with graded amounts of a soluble phosphate upon a high fixing area of Kauai. He reports the following data:

Treatment (Lbs. P_2O_5/acre)	Recovered (in single extraction Lbs. P_2O_5/acre)
0	0
2000	2.5
4000	50.0
6000	97.5
8000	250.0

It is significant to note that quadrupling the application, i.e., from 2000 to 8000 pounds, increased the water soluble P_2O_5 not *four,* but *one hundred* times—these findings having been made four months after application. Thus it appears that even in soils which have very high fixing power and providing heavy applications of phosphate are made, a considerable amount of soluble nutrient may remain available to the plant during the progress of fixation.

On the other hand, as mentioned previously, we have found that if phosphate present in the soil solution is removed by leaching, a release of phosphate from the fixation complex to the soil solution follows and that by successive leaching a large quantity of the fixed phosphate can be brought back into solution. Where larger amounts have been fixed, it is possible to release greater quantities.

The progress in the greenhouse experiment of surface feeding by cane on insoluble prosphates indicates that sugar cane can derive ample phosphate from the simpler, insoluble phosphate compounds. On the other hand, our researches have caused us to infer that very probably phosphate is absorbed by some of our soils in such a way as to form complex compounds which are probably not as soluble nor as available to plants as the simpler ones.

Soil Organic Matter as Affected by Applications of Phosphates

It has been known for a number of years that strongly alkaline solutions extract large amounts of dark colored organic matter from soils. This is usually described as organic humus. The term "humic" or "humus" is indefinite in meaning and covers a mixture of several slightly known and some unidentified compounds.

It appears that not alone strongly alkaline solutions, but probably any well-buffered* solution, even at a pH as low as 3.0 to 4.0, will extract some organic matter from soil. Unbuffered neutral or moderately acidified solutions, such as those containing nitrate of soda, or muriate of potash, do not have any appre-

* The term "buffer" has appeared previously and will be used occasionally in the discussion which follows. A buffer is a substance which, when added to another in a solution, causes a resistance to any change of acidity or alkalinity, even upon the addition of acids or alkalies. Some common buffering agents are: animal blood, certain acetates, phosphates, borates, etc.

ciable extracting power upon soil humates. It is also true that nitrates, chlorides, sulfates, etc., are not absorbed or fixed by soil to the extent that are phosphates.

Solutions of phosphates, such as ammonium phosphate, are very well buffered. Davis has found that such solutions can extract large amounts of organic matter from a soil. He found that the amount of matter extracted depends somewhat upon the pH but more upon amount of phosphate applied and is not very great for such applications as 100 pounds P_2O_5 per acre. But for larger applications considerably more organic matter becomes soluble. Davis has determined that if muriate of potash, sulfate of ammonia, etc., are applied along with the ammophos, the extraction is decreased somewhat, but not very greatly. Furthermore, even when these slightly buffered compounds have been applied, successive leaching with pure water will result in removal of large amounts of organic matter, that is, provided that sufficient ammophos has been employed.

It may develop, therefore, that in practice wherever large amounts of ammophos are applied to a high fixing soil, either singly or along with other fertilizer, not alone will a great deal of organic matter be dissolved, but subsequent leaching by rain or irrigation may carry it into the soil solution where it may be utilized by the plant or pass into the subsoil. We do not at present know the agricultural significance of this finding, but hope that additional light will be thrown on it in future researches as planned by Davis and developed from this important lead.

Base Exchange in Fixation

The subject of base exchange or base replacement has been studied extensively all over the world and to some extent by ourselves. We do not propose to discuss this subject except in the narrow way in which it is related to phosphate absorption.

If a solution of ammonium sulfate or potash nitrate is applied to a soil, a part of the ammonium or potash will be absorbed. It is believed to have reacted in some way with solid constituents of the soil containing sodium, potassium, magnesium, calcium, etc., in such a way that some of the latter group are exchanged for the introduced ammonium or potassium and are therefore made soluble, whereas pure water might bring very little of these bases into solution.

When ammonium or potassium *phosphate* is applied to a soil an amount of ammonium or potassium, it is thought, replaces other bases to an extent of at least five or ten times as much as would occur were a sulfate or muriate used instead. It appears that in the case of phosphate fixation, there is a corresponding fixation of at least part of the basic group. The agricultural significance of these facts is not at present clearly understood, but it is evident that they may be of outstanding importance with respect to such matters as the form, time and number of applications of phosphate fertilizer which should be made for any given soil or crop during a growing cycle.

Geographical Variability of the Phenomenon in Hawaii

Excessive phosphate fixation is found in the soils along the Hamakua coast. We believe it would prove of value to study pronounced characteristics of fixation in this vicinity and to correlate data in a comprehensive manner so as to consider the problem from a geographical viewpoint as we pass from the high fixing soils in

this dry belt progressively through the rain belt to Hilo. The soils of the Manoa substation are also very high phosphate fixers. But meager supplies of readily soluble potash are found in certain other Manoa soils. A study in this region, therefore, involves not only phosphate fixation, but includes the subject of the deficiency of potash. On the island of Kauai, Ayres has determined that fixation is most pronounced in the soils of higher elevation in the district of Kilauea. In his survey of that island by plantations from Kilauea to Makaweli, it was learned that in general and with normal soils the degree of fixation became less pronounced in moving progressively west toward Makaweli. Fields were found in the latter region where fixation of applied phosphates was relatively low. It was also found that the most fertile areas in this district were regions where fixation was least pronounced and that in growth failure or other poor areas the propensity to fix phosphates was markedly greater.

It was also shown by Ayres that the subsoils of Kauai are capable of much greater fixation than are the corresponding surface soils. This information is of importance when considered in connection with the fertilization of typical shallow surface soils of that island.

Conclusions

No panacea for phosphate fixation can be prescribed. Nevertheless, certain possibilities suggest themselves, some of which have been tried out in practice. It seems logical that each soil should be considered as an individual problem instead of attempting to apply a general rule.

The cases which naturally arise when one considers the relation between fixation and availability may possibly be grouped into four main types:

(1) The soil has a relatively low fixing power and a high content of phosphate, a condition frequently found in lowland soils. This soil may be fertile if there are no other difficulties and, in any event, it seems unlikely that much response to phosphate fertilization should be expected.

(2) The soil has a low relative fixing power and a low content of phosphate. This soil should probably respond to soluble phosphate fertilizers, provided that some other difficulty is not the limiting factor in cane growth. Under these circumstances the type of phosphate used may be very important.

(3) The soil has a moderately high fixing power. Slight applications of soluble phosphates, such as 100 to 200 pounds of phosphoric acid, may not give response, although larger but in many cases economically reasonable applications, such as 300 to 500 pounds, may increase the yield, other things being equal. It is reasonable to believe that once the level of phosphate content has been raised by an application of 400 pounds of phosphoric acid, for example, subsequent applications can be much lighter. Again, the form of phosphate chosen may be of very great importance.

(4) The soil has a high fixing power. In this case if sufficient soluble phosphate were to be applied undoubtedly it would be possible to overcome the fixation. But the amounts required may be absurdly uneconomical. In some cases, it has been found that lesser amounts will show no response at all, although phosphate deficiency may be pronounced.

As one means of side-stepping fixation it may be found possible to substitute moderate amounts of *insoluble* phosphates for the soluble forms. Insoluble phosphates will not be fixed by the soil. Certain of these compounds, notably reverted phosphate, appear at present to be very good sources of phosphatic food, at least under certain conditions. In a high fixing soil a combination of reverted and raw rock may prove an ideal phosphatic addition.

While soluble silica has been shown to effectively reduce fixation its employment for this purpose is uneconomical in view of the present prices of silica and of phosphates.

Soils treated with normal quantities of molasses have a lower fixing capacity for phosphates than untreated soils. The duration of the effect has yet to be determined.

Where subsoils are higher in fixing capacity than the corresponding surface soils it is important, when applying soluble phosphate to insure its placement in the lower horizon of the surface soil providing this layer is of sufficient depth to surround adequate portions of the feeding roots.

The addition of successive increments of phosphate to a soil results in an increasing proportion of the total applied phosphate remaining unfixed and hence available for use by the plant.

One of the most promising methods of applying phosphate in a form such that it will be available to the cane plant, but will not be fixed by the soils is believed to consist of the use of fertilizer briquettes carrying a *soluble phosphate*. It has been demonstrated that properly made briquettes will remain intact in the soil for some months and will very slowly yield their fertilizer nutrients to the plant roots. A mass of roots completely surrounding a briquette will protect it from the fixing soil and will have the first chance to absorb the phosphate fertilizer as it slowly leaches from the briquette. In addition, potash and nitrogen can be supplied in the briquette. In soils from which potash is very rapidly leached the briquette will aid in the retention of this necessary plant food.

Summary

1. Heavy phosphate fixation may be anticipated in a highly colloidal soil.

2. Applied soluble phosphates may be precipitated in a sandy or other soil in an insoluble form. In such a case the phosphate may or may not be rendered difficult for the plant to absorb.

3. Soil particle size, total soil areas exposed to action of soil solution and ratio of colloids to non-colloids in any soil are factors of importance in the phenomenon of phosphate fixation.

4. The cane plant can and does obtain adequate quantities of phosphate from insoluble granulated phosphates when grown in quartz sand and supplied at the same time with a balanced ration of other essential foods by nutrient solution. In the order of availability to the cane plant in sand cultures may be mentioned: Reverted phosphate, aluminum phosphate, ferric phosphate, tricalcium phosphate, and, lastly, raw rock phosphate. The responses to these forms of insoluble phosphates in soil studies have yet to be determined.

5. There is reason to believe that the crop can feed upon applied soluble phos-

phates during the time that fixation is taking place in the soil. The duration of this period is variable for soils having different characteristics.

6. Evidence is at hand supporting the probability that even after applied soluble phosphate have become fixed in the soil and the plant absorbs the available supply in the soil water solution additional phosphates redissolve from the fixed reserve and enter the soil solution again. The process appears to be continuous, and in the absence of removal by leaching, or by the plant, the action will continue until a balance has been established between the phosphate in the soil solution and that residing in the fixed reserve. When the rate of transfer is below the requirements of the plant (as it is in many cases) then phosphate starvation occurs.

7. In many respects moderate fixation of phosphates by the soil is of distinct advantage to the crop and grower. The problem of excessive leaching is absent—in some cases the phosphate nutrient may pass into the soil solution in continuous and progressive amounts as it may be needed. The fixed phosphate may thus function as a near-by reserve immune from leaching or other loss.

8. The choice of type of phosphate fertilizer may eventually prove of great importance. The solubility of other nutrients and the movement of soil organic matter into the soil solution are factors which appear subject to some control by the judicious use of commercially available phosphate types.

9. In many soils phosphate fixation is severe enough to result in deficient nutrition when fertilizer applications of 100 to 200 pounds of phosphoric acid, as soluble phosphate, are made, but if the degree of fixation is not too great, larger, but moderate applications such as 300 to 500 pounds may be sufficient to support good growth.

10. In soils which have very high fixing power, it is possible that phosphate applied as an insoluble compound may be sufficiently available and yet not be fixed by the soil.

11. We believe that possibly fertilizer briquettes will constitute a very useful means of applying insoluble phosphates in conjunction with other nutrients.

12. As a rule subsoils show a higher fixing ability than the corresponding surface soils.

13. Disregarding convenience and economy, it has been found that molasses and/or soluble silica are effective in reducing the phosphate fixing capacity of soils.

14. The larger the application of soluble phosphate to a given soil, the greater is the proportion thereof which remains in water soluble, and hence available, form.

NOTE: Messrs. Davis, Ayres, Ward and Gow have in preparation detailed papers supplementing topics referred to or commented upon in this discussion.

Variation of Mineral Content of Sugar Cane With Age and Season

By Arthur Ayres

The need for a more comprehensive understanding of the manner in which various factors influence the mineral content of sugar cane is becoming increasingly evident. Problems are constantly arising which involve rates of nutrient absorption, inadequate nutrient supply, and the composition of canes produced under greatly varied environmental conditions. Frequently the problem is pathological. In the cane plant, for example, a condition of disease may result from factors associated with a deficiency of some one or more nutrients. The existence of such a pathological state may often be verified by supplying the deficient element in amounts adequate to restore the plant to normalcy. Or, again, the physiological condition coincident with the presence of the malady may be induced in otherwise healthy cane plants by depriving them of the element in question. The chemist may cooperate in the pathological study by examining chemically the mineral content of abnormal specimens. Obviously, however, before he can state by what measure the concentration of a particular nutrient departs from that found in the normal plant he must have a knowledge of the composition of the normal plant as well as of the factors by which it is influenced.

It is the purpose of the investigation discussed in this paper to study the effect of age and season upon the nutrient content of the sugar cane plant. This work may also properly be considered as preliminary to a study now in progress which is designed to greatly augment our very limited knowledge of the rates of absorption of the major soil nutrients. The latter phase of the investigation bears directly upon the important question of time of fertilization.

Maxwell (1), at this Station (1900); Browne and others (2), in Louisiana, and more recently investigators both here and elsewhere have shown conclusively that the ash content of sugar cane differs very greatly with different varieties, even when grown under practically identical conditions of soil and climate. The work of Hall (3), at Rothamsted (1905), established the fact that the composition of plants in general is a function of their age. Johnson (4) cites voluminous data which support this contention. Cane composition studies reported by Stewart (5), Ayres (6) and more recently by Deomano (7) in the Philippines, amply illustrate the influence of age and season upon the mineral content of sugar cane. It is a well-known fact that the concentration of nutrients in the soil solution affects their rate of absorption by the plant. It is further known that the condition of the individual plant, that is, whether healthy and vigorous or diseased and stunted, is a factor affecting the amount and composition of its ash.

From these considerations it is apparent that a proper understanding of the subject must of necessity include a knowledge of the manner in which these factors influence the mineral composition of the sugar cane plant. Realizing the need for such an understanding and believing that a study of the effect of age and season upon absorption should logically precede inquiry into related factors, an experi-

ment, designed to yield this information for the variety H 109, was installed in the Makiki area in the fall of 1931. While the experiments at the Oahu Sugar Company, Ltd. (5), and the Waipio Substation (6), as previously stated, gave evidence of pronounced variation in the composition of the ash there was some

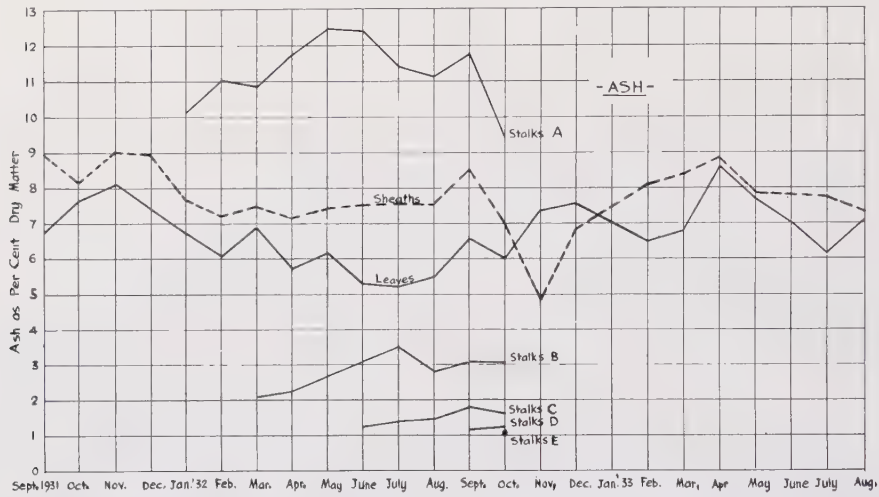

-ASH-
Stalks A
Sheaths
Leaves
Stalks B
Stalks C
Stalks D
Stalks E
Ash as Per Cent Dry Matter
Sept. 1931 Oct. Nov. Dec. Jan.'32 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan.'33 Feb. Mar. Apr May June July Aug.

Fig. 1. A comparative study of the ash content of different parts of the cane plant at various stages of growth. Data presented as percentage of dry matter.

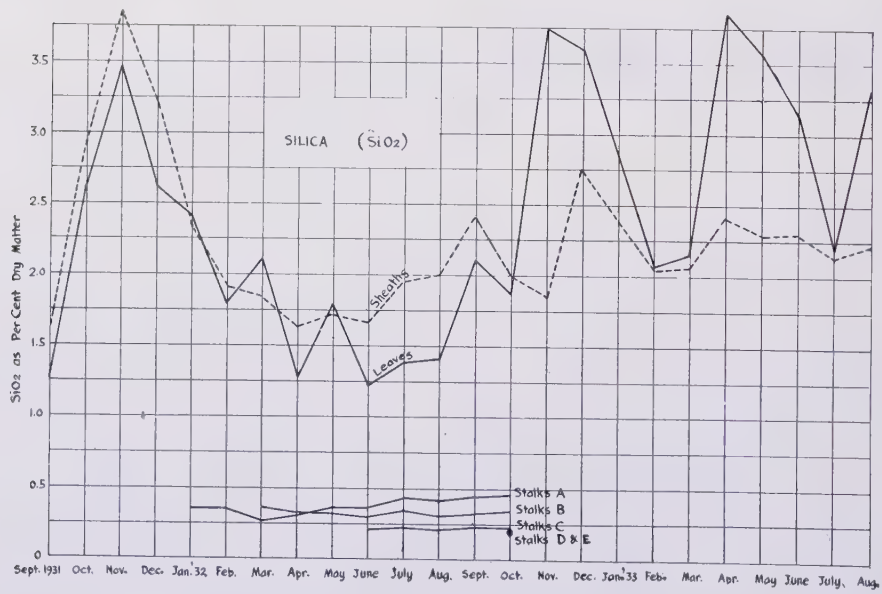

SILICA (SiO2)
Sheaths
Leaves
Stalks A
Stalks B
Stalks C
Stalks D & E
SiO2 as Per Cent Dry Matter
Sept. 1931 Oct. Nov. Dec. Jan.'32 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan.'33 Feb. Mar. Apr. May June July. Aug.

Fig. 2. A study of the silica content of different parts of the cane plant as the crop proceeds. Data presented as percentage of dry matter.

uncertainty as to the part played in the observed changes by the applications of potash, phosphates and their accompanying elements. In order to eliminate the necessity for applications of phosphoric acid and potash, with the resultant effects upon nutrient absorption and the equilibrium of the soil system, a fertile piece of

Makiki soil was selected for this work. One per cent citric acid extract of this soil yielded upon analysis the following results (dry weight basis):

0.402	0.776	0.026	0.236
Silica (SiO_2)	*Lime* (CaO)	*Potash* (K_2O)	*Phosphoric Acid* (P_2O_5)

Experimental

The experiment, involving approximately 1000 running feet of line, was installed for us by the agricultural department in Field 8, Makiki, on August 22, 1931. The resulting germination of the seed was excellent. Adequate guard lines protected from border effect the region from which samples of plant material were to be taken for analysis. Cane samples were obtained at monthly intervals with a single exception during the period of tasseling, beginning one month after planting and continuing until the crop was harvested on August 22-23, 1933. The samples were selected in accordance with a definite, predetermined plan, which, it was felt, was well suited to the purpose of the investigation. The number of stalks taken at each period was 20, except at the ages of 1 and 2 months, when, for purposes of analysis, additional material was required. Not more than a single stalk was removed per stool and at all times effort was made to obtain composite samples which represented all of the plant material available for the purpose. The plants comprising the sample were segregated into portions, when the material was present, as follows:

Description of Plant Part	*Herein Referred to As*
Green portions of leaves	Leaves
Green portions of leaf sheaths	Sheaths
From tip of growing point six inches down stalk	Stalks (A)
From base of Stalks A three feet down stalk	Stalks (B)
From base of Stalks B three feet down stalk	Stalks (C)
From base of Stalks C three feet down stalk	Stalks (D)
From base of Stalks D three feet down stalk	Stalks (E)
Fuzz	Fuzz
Tassel stalks	Tassel stalks

The division of the cane stalks as outlined above is largely arbitrary and was made in the stated manner for the purpose of determining the variation in mineral content within this physiologically continuous system. The greatest care was exercised in the preparation of the samples to remove all adhering foreign material which would affect the analytical results.

The fertilization of the experiment was as follows:

September 29, 1931	NH_4NO_3	N = 50 lbs./acre
November 27, 1931	NH_4NO_3	N = 100 lbs./acre
February 7, 1933	$(NH_4)_2SO_4$	N = 50 lbs./acre
	Total	N = 200 lbs./acre

The crop passed through the first winter without tasseling. As a consequence of tasseling the second winter, with the resultant abundance of lalas and the associated changes in the system which we had been examining, sampling of all parts

of the stalk was discontinued at that time. The basic analytical data resulting from the study are presented in the table in two forms; in one case as per cent of the dry matter and in the other as per cent of the ash. Both for reference pur-

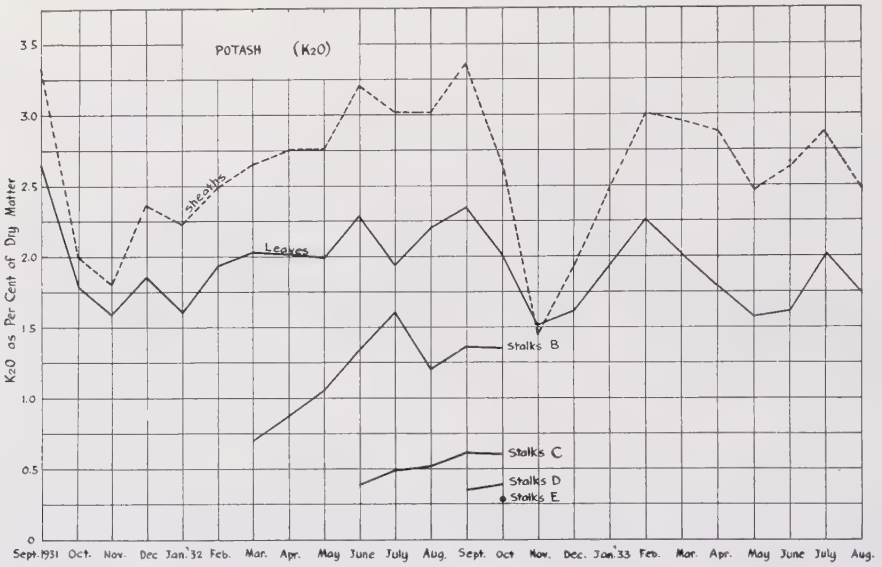
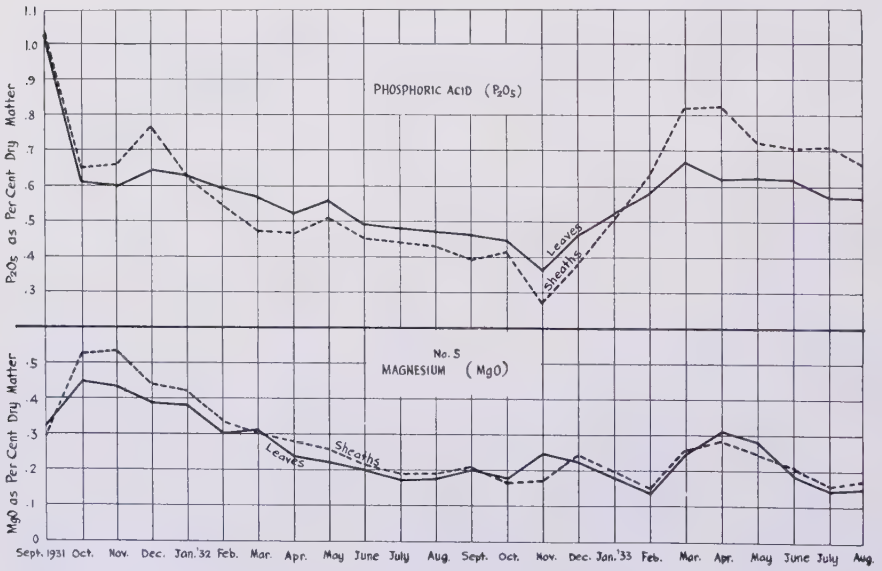


Fig. 3. A study of the potash content of various parts of the cane plant. Results expressed as per cent of dry matter.



Figs. 4 and 5. A study of the phosphoric acid and magnesium content of the leaves and sheaths of the cane plant. Results expressed as per cent of dry matter.

poses and in order that the reader may visualize at once the nature of the changes which were found to occur in the mineral composition of the crop, much of the data have been presented graphically. (The writer was ably assisted in the analytical work by E. K. Hamamura, analyst.)

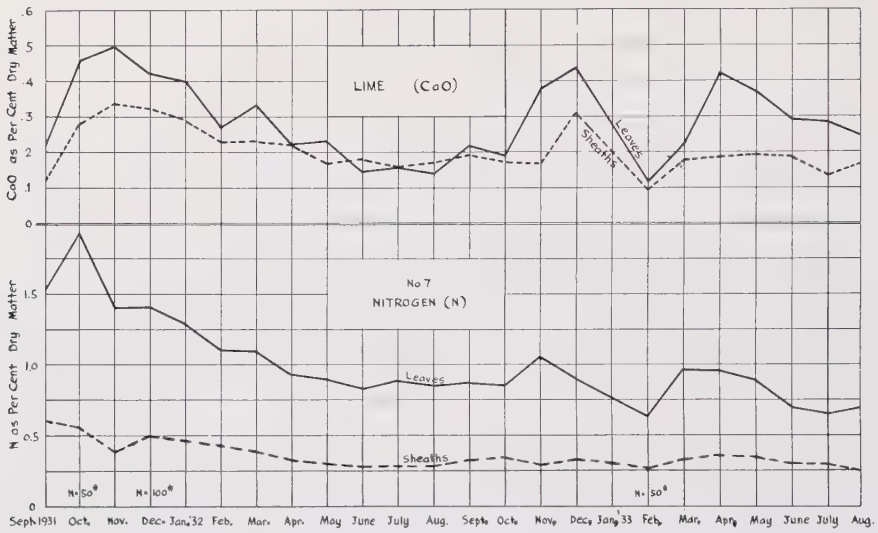
Discussion of Results

From even a cursory examination of the results it is evident not only that the concentrations of the inorganic nutrients in the various parts of the cane plant are very far from being constant throughout the course of the crop, but the behavior of certain elements with respect to their regional distribution is very unlike that of certain others. For instance, between the ages of 1 and 3 months, while the content of phosphoric acid and of potash in the dry matter of the leaves decreases by approximately 40 per cent, that of magnesium rises by some 35 per cent, that of lime by 145 per cent and of silica by 175 per cent. Throughout the entire period of growth there is maintained a most striking similarity in the manner in which silica, lime and magnesia vary, while in direct contrast, is that of the nutrient potash, the concentration of which in the leaves and sheaths varies inversely with that of the three constituents just named. With the noteworthy exception of nitrogen, the concentrations of nutrients in the leaves and sheaths are of much the same order. Marked similarities are found in the general direction and rate of change of mineral content in these two organs of the cane plant.

The composition of the stalk in the vicinity of the growing point (top 6 inches) is very different from that of any other part of the plant. While the ash content of the more remote portions of the stalk is in the neighborhood of 1 per cent, in the section just referred to it runs as high as 12.5 per cent of the total dry weight. This region is found to contain the highest concentrations of the elements nitrogen, calcium, magnesium, phosphorus and potassium. In view of the large quantities of potash which are always found in the meristem and active organs of plants in general, it is not particularly surprising that we find this nutrient alone comprising as high as 6 per cent of the total dry weight, or 45 per cent of the ash in this region of pronounced cellular activity. Reference to Fig. 1 shows a very marked drop in mineral content as we pass from the top 6 inches of stalk to the succeeding 3-foot segments. This diminution in the ash content is maintained, though in ever lessening degree, as the base of the stalk is approached. Not only is this true of the ash, but it is equally true of each component of the ash, as well as of nitrogen. However, this seemingly consistent relationship no longer obtains when we eliminate from our considerations sugars, fibers and other combustible organic materials and reëxamine the situation on the basis of the composition of the ash. In this clarified picture we see that the less readily translocated substances silica and phosphoric acid are actually increasing in the ash as we move in the direction of the older part of the stalk, whereas the concentration of the very mobile potash rapidly diminishes. This relationship is very clearly evidenced in Fig. 13.

It is of interest to note that sharp changes occur in the direction and rate of change of the mineral composition of the leaves and of the sheaths at roughly the following periods: 3, 15, and 20 months. Generally, these changes are more pronounced in the cases of those elements which are found in the plant in larger amounts. It will be seen that the second period (15 months) is just 12 months or one year after the initial period. This suggests a seasonal effect. At the same time it is quite possible that the sharp increases or decreases which abruptly ceased at the end of the first 3 months were associated with the development of

the foliage and that the equally sharp changes observed at 15 months (November 23, 1932), were the result of physiological processes related to the preparation of the cane to tassel. The changes of the third period referred to may have resulted from the application of spring nitrogen in February, 1933, with the


CaO as Per Cent Dry Matter
LIME (CaO)
Leaves
Sheaths
N as Per Cent Dry Matter
No 7
NITROGEN (N)
Leaves
Sheaths
N. 50*
N. 100*
N. 50*
Sept. 1931 Oct. Nov. Dec. Jan. '32 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. '33 Feb. Mar. Apr. May June July Aug.

Figs. 6 and 7. A study of the concentrations of lime and nitrogen in different parts of the leaves; shown in percentage of dry matter at various stages of the crop.

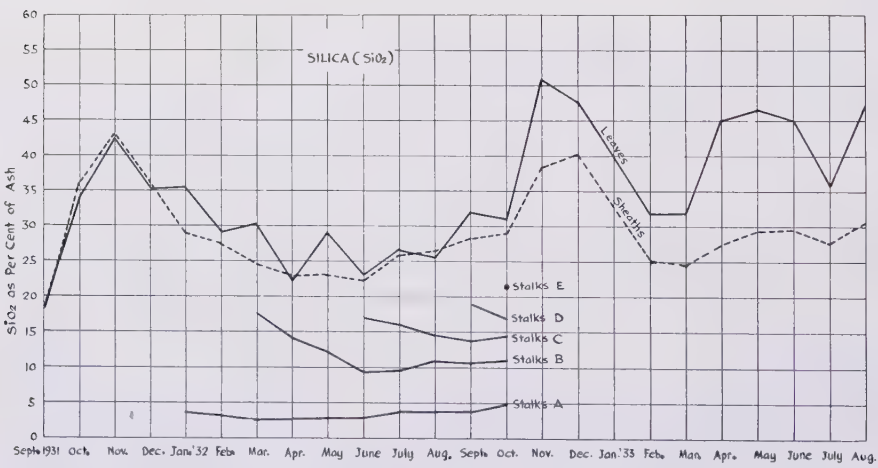

SILICA (SiO_2)
SiO_2 as Per Cent of Ash
Leaves
Sheaths
Stalks E
Stalks D
Stalks C
Stalks B
Stalks A
Sept. 1931 Oct. Nov. Dec. Jan. '32 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. '33 Feb. Mar. Apr. May June July Aug.

Fig. 8. Variation in silica content of the cane plant with development of the crop. Results expressed as percentage of ash.

resultant stimulation to growth, the latter having practically ceased coincident with tasseling.

Following is a hypothetical case which illustrates the manner in which information of the nature obtained in this work may be practically employed. Suppose specimens of H 109 cane grown under conditions similar to those of this experiment and suffering from a malady believed to result from insufficient potash, were subjected to analysis. Assume further that upon analysis the leaves

were found to contain potash in an amount equal to 1.5 per cent of their dry weight or, say, 20 per cent of their ash content. Is there, or is there not, a deficiency of this nutrient in the diseased plant? Reference to the data as pictured in Figs. 3 and 9 indicates that a potash content of the value found in the specimen is normal for certain stages of development, but decidedly below normal for others. Now, knowing the age of the specimen and bearing in mind the assumption that it was grown under conditions similar to those which obtained in this experiment, we can say, within certain limits, whether the pathological condition in the plant is, or is not, associated with a potash deficiency. From this simple example the necessity for investigation along lines similar to those of the present

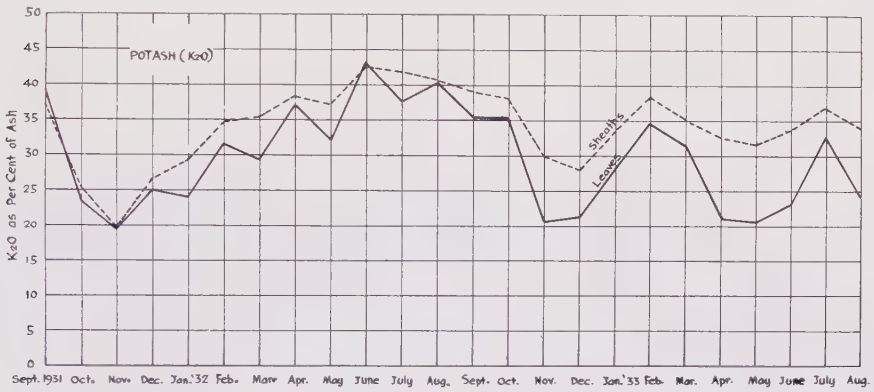


Fig. 9. Variation in potash content of leaves and sheaths of the cane plant as the crop proceeds. Results expressed on ash basis.

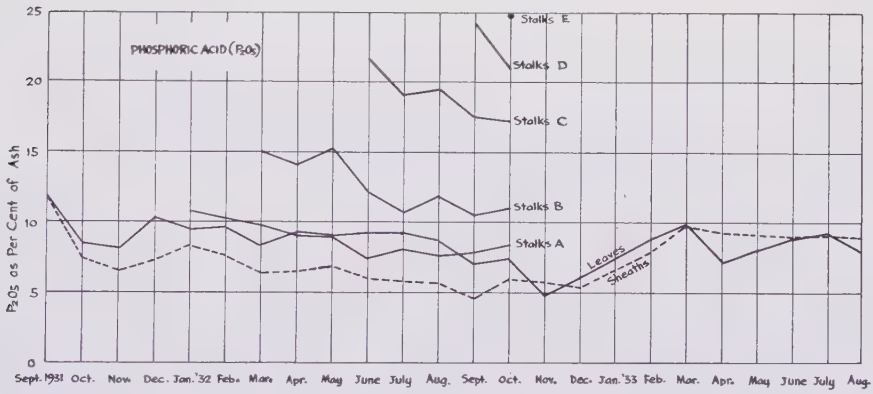
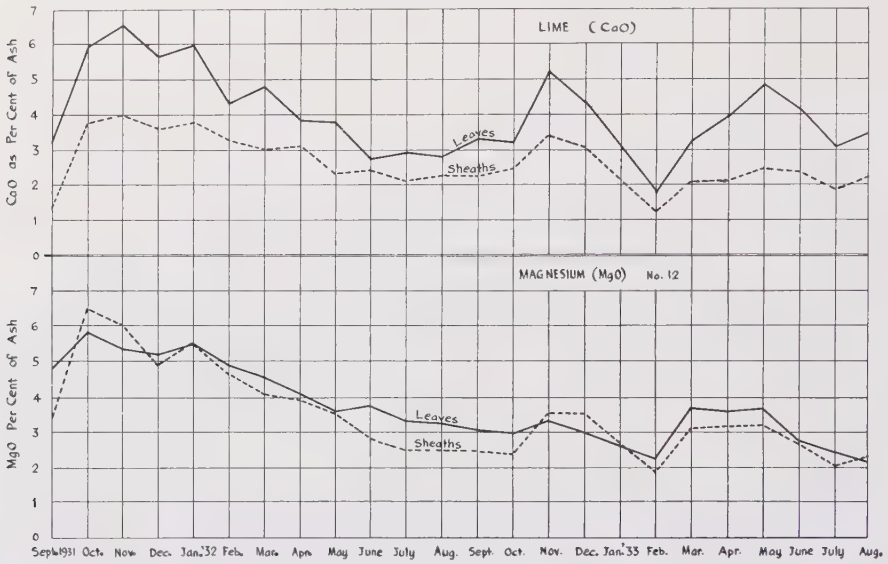


Fig. 10. A study of the variation of the phosphoric acid content of different parts of the cane plant as the crop proceeds. Results expressed on basis of ash.

study becomes apparent if we are to be in a position to deal adequately with cases of unbalanced nutrient conditions in the cane plant resulting from disease, soil nutrient deficiencies, etc. It is highly probable that, as W. W. G. Moir has repeatedly suggested, we may find the principal consideration to be not the actual concentration of a given nutrient, but rather the quantitative relationship which the element in question bears to the other mineral components of the plant.

The experiment is to be continued as the ratoon crop through the same cycle

as that of the plant. We will thus be enabled to compare, at monthly intervals, the mineral composition of the two crops. In an investigation conducted jointly by the department of chemistry and the Oahu Sugar Company, Ltd., in 1931, the writer (8) showed that the concentration of nutrients in the several parts of the


LIME (CaO)
CaO as Per Cent of Ash
Leaves
Sheaths
MAGNESIUM (MgO) No. 12
MgO Per Cent of Ash
Leaves
Sheaths
Sept. 1931 Oct. Nov. Dec. Jan. '32 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. '33 Feb. Mar. Apr. May June July Aug.

Figs. 11 and 12. Studies of the lime and magnesium content of leaves and sheaths of the cane plant as the crop proceeds. Results expressed on percentage of ash.

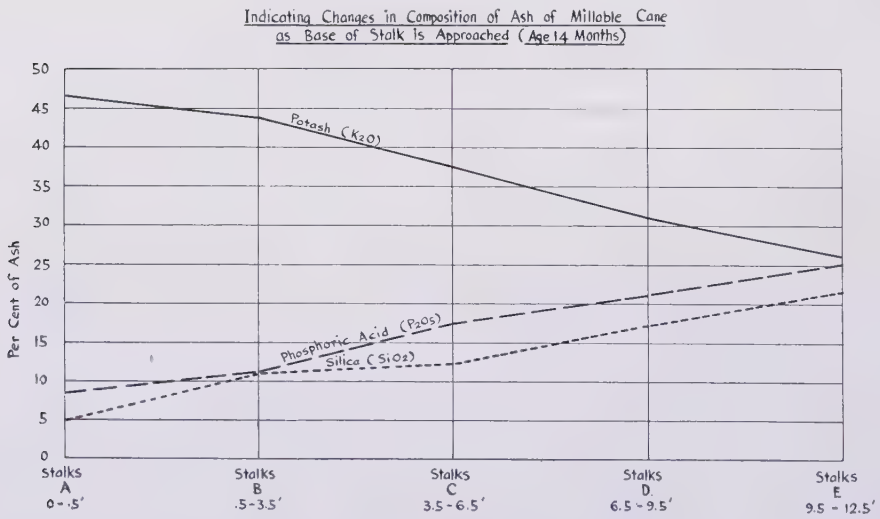

Indicating Changes in Composition of Ash of Millable Cane as Base of Stalk is Approached (Age 14 Months)
Potash (K2O)
Phosphoric Acid (P2O5)
Silica (SiO2)
Per Cent of Ash
Stalks A 0 - .5'
Stalks B .5 - 3.5'
Stalks C 3.5 - 6.5'
Stalks D 6.5 - 9.5'
Stalks E 9.5 - 12.5'

Fig. 13. The relationship shown here between the nutrients potash, phosphoric acid, and silica probably indicates the translocation of potash from the older to the more recently formed parts of the cane plant.

cane plant were generally lower in the ratoon than in the plant crop, the comparison being based upon the analysis of material obtained at harvest. This finding will receive attention in connection with the present investigation. The study

relative to the ratoon crop will be so extended as to permit the measurement of the rate of absorption of the principal soil nutrients by the total aerial portion of the cane plant. The results of this work are calculated to indicate not only the manner in which the mineral content of the plant changes with age and season under stable conditions of nutrient availability (i.e., without applications of potash and phosphoric acid), but also the periods of growth during which heavy demands are made upon the soil for these materials.

Nothing approaching a complete exposition of the findings of this study has been attempted at this time. Rather has it been the purpose of this paper to point out the high lights of the preliminary results, something of the need for such information, its practical application and to defer additional discussion pending further progress.

Note: The writer wishes to express his appreciation to Dr. Hance and Mr. Davis of this department for assistance and counsel, and to Messrs. Doty and Sa Ning of the department of agriculture for the installation, care and harvesting of the experiment.

Summary

1. A study has been made at monthly intervals of the effect of age and season upon the chemical composition of the sugar cane plant.

2. Graphs are presented which illustrate the changes occurring in the nutrient content of leaves and leaf sheaths with age and season.

3. The concentrations of the elements for which analysis was made were found to vary greatly, in a generally orderly manner, with the development of the crop.

4. Marked similarities exist in the direction and rate of change of concentration of certain of the elements investigated.

5. The nutrient content of leaves and sheaths was generally found to be very similar throughout the course of the crop.

6. The ash content of the stalk falls off progressively in the direction of the older region of the stalk.

7. The silica and phosphoric acid content of the ash of the stalks increases very markedly as the base of the stalk is approached, while that of potash decreases in an equally pronounced manner.

8. The concentrations of nitrogen, phosphoric acid, potash, lime and magnesia are greater in the region of the growing point than in any other part of the cane plant. With the exception of this portion of the stem the concentrations of all the elements for which analysis was made are highest in the dry matter of the leaves and sheaths.

9. Abrupt changes in direction of change of nutrient content of leaves and sheaths with the development of the crop are generally coincident with (a) attainment of mature foliage and commencement of stalk formation (3 months), (b) preparation of crop to tassel (15 months), and (c) lala development (20 months).

10. The order of nutrient concentrations in various parts of the cane plant is generally as follows:

Leaves

$$SiO_2,\ K_2O > N > P_2O_5 > CaO,\ MgO$$

Sheaths

$$K_2O,\ SiO_2 > P_2O_5 > N > MgO > CaO$$

Region of Growing Point (Stalks A)

$$K_2O > N > P_2O_5 > MgO > SiO_2,\ CaO$$

Mature Stem (Stalks C)

$$K_2O > P_2O_5 > SiO_2 > MgO > N > CaO$$

11. The need for further study of factors influencing the mineral content of sugar cane in relation to disease, plant food deficiencies and undesirable conditions resulting from unbalanced nutrient content is discussed.

Literature Cited

(1) Maxwell, W. 1900. Div. of Agr. and Chem., H. S. P. A. Expt. Sta. Bull. No. 6.
(2) Browne, C A., and Blouin, R. E. 1907. The chemistry of the sugar cane and its products in Louisiana. La. Exp. Sta. Bull. No. 91.
(3) Hall, A. D. 1905. The analysis of the soil by means of the plant. Jour. Agr. Sc. I, pp. 65-88.
(4) Johnson, S. W. 1915. How crops grow. Orange Judd Co., New York.
(5) Stewart, G. R. 1929. Periodic harvesting of H 109 cane at Oahu Sugar Company, Ltd. Reports of the Assn. of Hawn. Sug. Tech., pp. 199-220.
(6) Ayres, A. 1930. Cane growth studies at Waipio Substation. Hawaiian Planters' Record, XXXIV, pp. 445-460.
(7) Deomano, F. V. 1931. A study of the chemical composition of four sugar cane varieties of the same age and grown under similar conditions. Philippine Agriculturist, XX, pp. 139-153.
(8) Ayres, A. 1931. A comparison of nutrient extraction by H 109 plant vs. ratoon crops at Oahu Sugar Company, Ltd. Unpublished H. S. P. A. Expt. Sta. Report (August 21, 1931).

CHEMICAL COMPOSITION OF PLANT PARTS

Age (Months)	Plant Part	Ash % D.M.	SiO_2 % D.M.	SiO_2 % Ash	CaO % D.M.	CaO % Ash	K_2O % D.M.	K_2O % Ash	MgO % D.M.	MgO % Ash	P_2O_5 D.M.	P_2O_5 % Ash	N % D.M.
1					.216				.322				
	Leaves												
	Stalks A												
			1.91										
			.352										
			2.09										
			1.84										
	Stalks A		.268										
	Stalks B												
	Stalks A		.313										
	Stalks B												
			.363					37.2					
								37.1					
	Stalks B							38.6					
10								43.0					
								42.7					
	Stalks A												
	Stalks B							42.7					
								39.8					
1													
								41.9					
	Stalks A							38.1					
								45.4					
	Stalks C							39.9					
1													
	Stalks C							40.0					
	Stalks D			19.1									
				31.2									
	Stalks A												
	Stalks B												
	Stalks C												
	Stalks D	23											
	Stalks E	1.94											

NOTE. D.M. refers to Dry Matter

Age (Months)	Plant Part	Ash % D.M.	SiO_2 D.M.	SiO_2 % Ash	CaO % D.M.	CaO % Ash	K_2O % D.M.	K_2O % Ash	MgO % D.M.	MgO % Ash	P_2O_5 D.M.	P_2O_5 % Ash	N % D.M.
12					.382	5.19		20.5		3.93	.303	4.93	1.06
					.365					3.25	.272	5.75	.298
										6.09	.755	13.1	1.69
											.586	13.2	.787
										3.91	.463	6.13	.907
											.379	5.53	.336
										4.98	.702	9.70	1.35
										3.15	.464	11.1	.364
										2.24	.379	8.91	.642
										1.92	.630	7.82	.2
										3.68	.675	9.96	.970
										3.11	.822	9.83	.332
										3.62	.619	7.23	.968
										3.22			
										3.70	.624	8.17	.902
											.725	9.28	.350
											.622	8.89	.702
										2.71	.705	9.05	.319
13										2.68	.508	9.25	.602
										2.46	.710	9.20	.200
24										2.09	.575	8.32	.698
										2.18	.658	9.03	.264

D.M. refers to Dry Matter

Water*

By Charles S. Judd
Territorial Forester

WATER! The cry of the wounded on the battlefield, of the traveler lost on the desert, and of shipwrecked mariners adrift in a boat; that which is usually taken for granted, and is never missed until the well goes dry; the greatest solvent known; a good servant, but a most powerful and destructive master; the lack of which is the most effective agency in limiting human settlements; a powerful factor in changing the configuration of the earth's surface; and what for centuries was considered and is still spoken of as an element, and what, when pure, is colorless, tasteless and odorless.

When the Indians of the southwestern deserts, where water was extremely scarce and was used with the greatest of parsimony, visited the white man's settlements for the first time and saw water produced by the mere turning of a faucet handle, like the water of Meribah which was brought forth out of the rock by the rod of Moses, they thought it magic.

Scarcely more than three years ago, immediately after a very severe major operation, my surgeon prescribed that in order to survive I must refrain from the use of water for two days. It was then that I knew for the first time what thirst really is and during my day and night dreams, I thought of a cool spring that gushed from a volcanic dike at the head of Waiahole Valley, of the dew-bedecked water bottle in the ice box at home, and of the crystal-clear streams of cool mountain water that I had often come across in my wanderings. How wonderful was the refreshment of the water from a tiny piece of melting ice which I was permitted to have toward the end of the second day.

When famished for water in the old goat-hunting days on the Kauai cliffs, muddy water collected in the imprint of a wild bullock's hoof has been more pleasing even that what, I am told, the finest of champagne tastes like. How grateful were we, in the old Honolulu days of inadequate surface water supplies, to dip the muddy water from the family bathtub, which the wise forethought of a provident mother had filled anent the emergency.

Water exists in the greatest quantity of any single substance and is absolutely necessary for our existence. It covers five-sevenths of the whole earth, and if the surface of the earth were smooth, without mountains or valleys, water would cover its surface uniformly to a depth of about two miles.

Plants and animals require water in surprisingly large quantities. It has been figured that a sunflower plant will use two pounds of water a day and the amount of water transpired each year by one acre of normal beech forest has been estimated at 1,200 tons. This is the equivalent of about 10.6 inches of rainfall per year. Very few forest types, however, transpire as much moisture as beech.

---

* Address by the retiring President, Hawaiian Academy of Science, Annual meeting, 1933.

We can realize how essential water is in sustaining life when we consider that the human body is about two-thirds water. Man can live without food for about two months, but can do without water only two or three days. As examples of the water content of the foods we use, rich milk contains about 87 per cent water, eggs 65 per cent, and cucumbers 97 per cent. For every pound of grain that is grown, for every pound of meat that is produced, many times their weight in water is required. A pound of bread is the equivalent of about 2 tons of water used by the growing grain. A pound of beef is the equivalent of 15 to 30 tons of water consumed by the beef animal, both directly and indirectly through feed. And if you are inclined to revel in vivid statistics, consider this: the adult who eats 200 pounds of bread and 200 pounds of meat in a year, consumes the equivalent of 4,400 tons of water—which ought to be enough to drown both him and the statistician who figured it out.

Water sprouts the seeds and feeds plants. A tree, like other forms of life, is engaged in the constant circulation of fluid through its tissues. Life processes, animal or vegetable, can go on only so long as each individual cell is surrounded by a fluid containing nutriment. To meet this demand and to provide for a large amount of evaporation, a tree passes up a great deal of water and this water, in the larger species of trees, will have to be lifted 200 and even 300 feet.

How is this supply of water taken to the top of such tall trees? This question, in the present stage of man's knowledge of physics, cannot be answered. We do not know, but Charles D. Stewart in the April, 1929, issue of *The Atlantic Monthly,* has presented some most interesting conjectures in connection with this phenomenon:

The lamp-wick principle, capillary attraction, will not go far in raising water. Water rises in a capillary or fine tube to a height in proportion to the fineness of the tube; and the viscosity of water is such that if the tube is very fine it will not rise at all. Capillary attraction would not raise water to the top of even a moderate-sized tree.

Root pressure or osmosis, a sort of powerful absorption due to unbalanced chemical pressure between the soil outside of the root membranes and the denser solute inside of it, has been taken into consideration. By cutting off a plant near the ground and fastening a glass tube upright on the stem, it is possible to ascertain the height to which its sap will rise by pressure from below. Under favorable conditions a grapevine will exert a pressure sufficient to raise a column 36.5 feet, while a birch has tested as high as 84.7 feet. This might seem a promising line of inquiry were it not that root pressure takes place in woody plants, in temperate zones at least, only in early spring, and especially in the morning.

It has been found that when a tree is evaporating the greatest quantities of water, on dry, hot days of summer, there is no root pressure whatever. Even if such pressures were not seasonable and unusual, they would not serve to send water to the tops of the tallest tree.

It has been proved beyond question that the rise of water in the tubes of a tree is caused by a pull from above. The law of an ordinary suction pump limits the lift of water to 33 feet. No invention can be made which will pull more than the laws of physics will enable it to. And 33 feet falls far short of reaching the top of a sequoia.

But water has got to go up those tubes to the top of a tree. It will and does. This being the case, scientists began to consider whether water in thin columns, as in these fine tubes in the sapwood, has not an actual power of coherence, a tensile strength, sufficient to stand a strong pull. Possibly, after all, water may be drawn up from the top as if it were a rope. Strange as it may seem, experimentation has gone quite far in

proving this to be the case. It seems that such a column of water has a power of coherence great enough to withstand the pull. And the osmotic force in the leaves, a strong pull of absorption, might be sufficient to raise the columns of water to the necessary height.

This is the theory that at present comes nearest to satisfying scientific minds but here a further difficulty presents itself. The rise of water depends upon evaporation. This flow persists when the air is saturated or the leaves are entirely submerged in water.

The rise of water in tall plants is a mystery but it is life that is at work.

It is when we consider the tree from the standpoint of evolution—a plant made to conquer difficulty, a sea creature living on land, a machine progressively put together to achieve the nearly impossible—that we begin to see its lofty waterworks in their full significance.

The tree was an idea in nature, a very bold and original idea based upon a fundamental patent; and the steps leading up to it were four. First came the primitive water plants, the thallophytes, floating freely about or, according to the latest views, living in the saturated soil along the shore. Second came the amphibious plants, such as the mosses; third the woody plants beginning with ferns; and fourth the most modern woody and two-sexed plants of this highly mechanized vegetable age.

The mosses crawled on their bellies up toward the dry land. Stealthily and cautiously the moss plant draws away from the water's edge, lying low. Finally the great idea came to pass in the form of the fern. Here was a vegetable mechanism with true, running roots, which the moss has not; and it possessed a woody stem provided with tubes for conducting water. With the invention of the fern, piping the water upward, while the roots struck down to bring it from below, nothing more was necessary to the making of a tree. It only remained for the stock company of cells to go ahead and, in modern parlance, construct a "bigger and better" plant.

Every cell in the top of a tree continues to be immersed in the life-giving water. Between a cell in the sea and one in the topmost twig there is no essential difference in situation. And the reason is that everything is done to control evaporation and hold it within bounds. Every leaf is coated with a preparation that most effectually seals it. Air can enter and water escape only through microscopic openings called stomata on the under sides of the leaves; and every stoma is capable of being opened or closed according to conditions. The whole trunk and every limb of the tree are jacketed in the protective, suberized bark. There is nothing more waterproof than bark, more stubbornly impermeable. It is because cork is so waterproof that it makes stoppers for bottles and gaskets for engines. It is because it is so impermeable that it is ground up to make linoleum. A tree, from head to foot, is armored against evaporation. Consequently its cells, though they hang in the very eye of the sun, are in water as wet as that which surrounded them in the sea.

Water is a compound of hydrogen and oxygen and although it is commonly spoken of as a liquid, it exists also in solid and gaseous forms. Water vapor is a normal component of the atmosphere, and when as much water has evaporated into the air as it is possible for it to hold, the atmosphere is said to be saturated. Under ordinary atmospheric pressure water becomes a vapor at 212° F. and solidifies at 32° F.

A feature of water, important in physiography, is its exception to the general law of expansion by heat. It is at its greatest density at 39.2° F. When heated from the freezing point, it contracts until it reaches 39.2° F., after which it expands. Conversely, when cooled from 212° F., it contracts until it reaches 39.2° F., when it again begins to expand. This expansion with freezing is of great importance, for it keeps the ice on top of the heavier masses of water and thus prevents the solid freezing of lakes and ponds, which would cause the death of the

animal life in their waters. On the other hand, it causes, in climates less salubrious than ours, the bursting of water pipes in freezing weather.

The waves of the sea exert almost unlimited power and could some device be found for using this power in operating machinery, the expense of many manufacturing processes might be reduced.

Every sea captain and veteran mariner knows of the terrific force of water as manifested in the waves of a storm, and many a ship has limped into port with her superstructure smashed and demolished by the relentless energy of the ocean waves.

The power from water was formerly used in hydraulic mines to wash gold-bearing gravel from the hills, and the same principle is used today for moving and settling soil in the construction of earth dams. This power has more lately been put to even intenser use and in the Westinghouse research laboratories tiny jets of water cut through the hardest steel alloys in a test for the purpose of determining the rate at which different metals wear away as they cut through a moisture-laden atmosphere at high speed. The hardest metals seem as soft as cheese when subjected to this water test.

Water is so slightly compressible that for most practical purposes it may be regarded as incompressible. For this reason it is utilized successfully in the hydraulic press, which depends for its action on the principle that a pressure exerted on any part of the surface of a liquid is transmitted undiminished and equally in all directions through the mass.

To make water available, huge expenditures are often made. An example of this is the new water supply system for Southern California, where water is at a premium. The new Colorado River aqueduct is the largest waterworks project in the world and will be 265.5 miles long from the Colorado River to a terminal reservoir and requires a pumping lift of 1,563 feet. Its carrying capacity will be one billion gallons per 24 hours. Construction cost, including interest charges, is estimated at $206,000,000.

Water power is, perhaps, after wind power, the most natural and at the same time the most economical source of energy. The term water power is something of a misnomer. The real agent is gravity, the fluid itself being the medium through which the action of gravity is transmitted to the prime mover. The total capacity of water-power plants in the United States at the end of 1930 was 14,884,667 horsepower.

We are indebted to the movement of water in the form of ocean currents not only for a marked influence on the distribution of temperature, but also for a wide dissemination of plants from land to land over the face of the globe. Seeds adapted to resist the effect of sea water may be carried by ocean currents to new lands. The seed of the milo, for example, can float a year in sea water without loss of germinative capacity.

Fourteen years after the destruction of all life on the volcanic island of Krakatao, fifty-three phanerogams had reached the island, from which it was estimated that 60 per cent had arrived by ocean currents, 32 per cent by wind agency, and only 4 per cent by fruit-eating animals or by man.

Dr. Forrest Brown has pointed out that we are indebted to Brazil for the derivation of the Hawaiian thistle tree (Hesperomannia) and that it must have been

brought here from the east coast of South America by ocean currents on its long journey through what is now the Panama Canal region when, during the Eocene period, this connecting link between North and South America was under water.

Ocean currents, therefore, as compared with such other agencies as winds and frugivorous birds, would appear to be, by far, the most efficient agency in the dispersal of seed-bearing plants.

To the ocean waters of this globe we are indebted for a large share of our food supplies by reason of the animal and plant life which they sustain. We are indebted to these waters for our maritime commerce and comparatively cheap methods of transportation which began after our forebears once rid themselves of the notion that the earth was flat and that if you should go too far out to sea you might fall off the edge of the world into oblivion. This method of cheap transportation by water extends far inland on some of our continents by reason of the large navigable rivers which penetrate their way to the ocean. These rivers became the early avenues of trade, which eventually prompted the improvement of river channels and ultimately the construction of canals.

A manifestation of the force of water in combination with wind is the so-called "waterspout," which is really a cloud and not the imagined solid column of water. A waterspout is the funnel cloud of a tornado and is formed in the same manner by the air whirling at terrific speed—perhaps 200 to 300 miles an hour. A partial vacuum is created by the centrifugal action of the vortex, the water vapor in the air is cooled by expansion and condenses to liquid drops. While it is true that above a certain height the column of a waterspout is only a cloud and is sometimes so thin that distant objects can be seen through it, the base of the spout is always surrounded by a quantity of flying spray, whipped up from the surface of the sea. In some cases, this water is carried up hundreds of feet.

Thus, a vessel running into a waterspout is generally deluged with water, and if the spout collapses at the moment of encounter, a veritable cloudburst occurs, such as might easily swamp a small vessel. In the early morning of March 30, 1923, the White Star liner *Pittsburgh,* while in mid-Atlantic, was struck almost head-on by a spout which the deck officers asserted was 40 to 50 feet wide and more than 70 feet high, as water filled the crow's nest that far above the waterline. Many tons of water dropped upon the forward superstructure. The bridge was wrecked, the chart room badly damaged, electrical connections were destroyed and the officers' cabins flooded.

The large amount of water that may be discharged by a waterspout is indicated by a case in which the spout came ashore at Swansea, Wales, in September, 1886. A spout was seen to travel from the adjacent bay to an eminence called Kelvey Hill. The latter is about 650 feet high and the upper part is almost vertical, while on the lower slope some rows of houses had been built. When the spout struck the hill great torrents of water rushed down the slope, burst through the upper row of houses and carried all their movable contents into the street below. Many people were washed from a back room into a front room, out of the door and down the hill. The amount of earth and rocks washed down by the torrent was estimated at 8,000 tons.

All civilization has passed through periods of excessive precipitation that have caused floods. The Bible tells us that life on earth was saved from water only by

Noah and his ark when forty days and nights of rain flooded the cradle of civilization.

It has been estimated that the yearly discharge by the streams on the mainland of the United States into the sea is 500 million tons of suspended material and that twice this amount is stranded upon lower slopes and deposited over flood plains, in the channels of streams, and even in the basins of reservoirs, where it is not needed and not wanted.

Furthermore, it is not known how much erosional detritus enters the ocean as drag material swept along the bottoms of streams. This debris thus swept along the bottoms of many streams travels rather after the manner of waves or of sand dunes drifting before the wind. Some particles of the bed load slide; many roll, the multitude make short skips or leaps, the process being called saltation. Saltation grades into suspension.

The almost inconceivable damage wrought by floods has been unquestionably increased in a great measure by the works of man in the stream channels, along the banks, and across the river valleys. Although the presence of enormous volumes of water at the times of flood may be considered nothing more or less than the acts of nature, still a large share of the blame for the resulting damage must be laid to man, not only for the positive harm done by the works of municipal and rural improvements, but also because of interference with the natural soil protecting cover.

Soil vandalism is the greatest economic problem facing the conservation forces of the United States today. Despite vast expenditures for agricultural education, a large part of the good farm soils are being despoiled at an alarming rate. The despoliation of our streams, while serious enough in itself, is merely a symptom, an inevitable concomitant of what is taking place upon the land.

The plan of stream control upon the land implies working with nature to repair the damage to land and to stream, instead of erecting enormous barriers against her relentless forces; it means an intelligent compromise with nature in order that land use may proceed safely and largely unimpeded, instead of a stupid conflict of brute strength with her. To some extent it probably means taking land which never should have been cultivated out of cultivation to be employed for pasture or forest.

The power of water as manifested in abnormal soil erosion constitutes one of the greatest problems now facing the United States. Under normal conditions rock decay keeps pace with soil removal in many places. Removal of forest growth, grass and shrubs, trampling by livestock, and breaking the ground surface by cultivation accentuate erosion to a degree far beyond that taking place under average natural conditions, especially on those soils that are peculiarly susceptible to rainwash. Under these conditions, soil removal by the rains exceeds the rate of natural soil formation and the soil that is washed out of fields can not be restored, except by those exceedingly slow natural processes of soil building that require, in many instances, centuries to develop a comparatively thin layer. Experts assert that the minimum rate of soil formation is not greater than one foot in 10,000 years.

Not less than 126 billion pounds of plant food material is removed from the fields and pastures of the United States each year. Most of this loss is from cultivated and abandoned fields and overgrazed pastures and ranges. The value of

these plant food elements, considering only phosphorus, potash and nitrogen, exceeds 2 billion dollars annually.

Of the heritage of over 650 million acres of readily arable land on the mainland of the United States, at least 21 million acres have gone out of cultivation because of destructive erosion alone. What it took nature 3,000 years to produce, man is now destroying in the short period of one generation.

The area of land eroded in the United States already exceeds the total area of arable land in Japan. The agricultural soil of a country is the nation's most valuable natural resource, yet less interest is usually shown in soil conservation than in any other conservation problems. The great volume of silt contributed to the floods of the Mississippi comes from the misuse of farm and pasture lands. The cure is to deal with the rainfall on lands upon which it descends and induce it to go into the soil in place instead of running off laterally and carrying the soil with it. The way to stop surface run-off is to require each parcel of land to take up its share of rainfall.

All the crops in the United States annually remove about 6 billion pounds of plant food from the soil, but erosion annually removes about twenty-one times as much.

As an example of what has happened on account of erosion, one county in the Atlantic Coastal Plain has 70,000 acres of former good farm soil, which, since clearing and cultivation, has been gullied beyond repair. In one place, where a school house stood forty years ago, gullies having a depth of 100 feet or more are now formed and these finger through hundreds of acres of land, whose reclamation would baffle human ingenuity. There are many deep gullies with steep or perpendicular sides on which no vegetation can find a footing. One of the largest has developed within the memory of the present generation, having started with the formation of a small gully from the run-off of a barn.

The decrease in acre yield of wheat in parts of the Wheat Belt, decrease in acre yields of corn in many sections of the Corn Belt, and decrease in acre yields of cotton in numerous localities in the Cotton Belt can be attributed largely to soil washing.

The question might well be asked: Where is a nation headed that is destroying the fertility of farm lands at a rate of 3,000,000 acres per annum?

When the mellow top soil is gone, with its valuable humus and nitrogen, less productive, less permeable, less absorptive, and more intractable material is exposed in its place. As a rule this exposed material is the raw subsoil, which, to be usable, must be loosened, aerated, and supplied with the needed humus to put it into the condition best suited to plant growth.

The practical problem lies almost wholly in retaining and passing into the soil the maximum of the precipitation. It is obvious that the erosional debris entering the streams adds to the volume of the water and increases the intensity of floods. Methods of soil conservation, chiefly terracing the land and the growing of trees, grass and other soil-binding plants, have been found effective in slowing down or controlling soil erosion by causing more water to be retained in the surface soil and to be stored in the subsoil.

Soil conservation is therefore somewhat synonymous with moisture conservation. Nothing will hold back all the water, of course, but enormous quantities can

be held temporarily or stored for summer crop use. Soil conservation, therefore, should be an important adjunct of any long-continued system of flood control.

The part of the rainfall which is absorbed into the soil where water is available in wells and springs and maintains the regularity of streams is the part which sustains life for both plants and animals.

A vegetative cover checks the excessive run-off by breaking the impact of raindrops on the ground, by intercepting a portion of the moisture before it reaches the surface of the ground, by extracting some of the moisture from the soil, so that it is capable of absorbing more water when rainfall occurs than would otherwise be possible, by adding to the humus content and loosening the consistence of the soil and thereby improving its absorptive and water-holding capacities, by the direct interposition of leaves and stems which help to keep the run-off spread out instead of concentrating its volume in gullies and which form nuclei around which other fragments of dead plants and other material collect to form miniature dams and terraces and further check and retard the run-off and by straining out and reducing the quantity of fine soil material in the water and thus rendering it more free to seep into the soil.

Vegetation is our most dependable ally in the control of the absorption of precipitation waters. The mantle of vegetation maintains, when unimpaired, what may be termed a geologic norm of erosion. We have no way of stopping effectively this geologic norm of erosion which, however, for well-vegetated regions is not excessive. The destruction of vegetation and conditions for its renewal may bring about, in inclined and steep topography, erosion which is much in excess of the geologic norm. Only this excess erosion is within human power to control, yet it may reach stages where control is beyond practical possibilities.

The extent of water control on watersheds is measured by the possibility of controlling erosion in excess of the geologic norm of erosion. Water control here is referred to watersheds and not to the engineering works of dikes, dams and the like. In other words, we have a measure of possible water control expressed in the silt content of run-off waters. We can measure our success in water control by our success in erosion control.

The irrigation problem in western United States is being further complicated by the silting of streams and storage reservoirs. The Elephant Butte reservoir on the Rio Grande River in New Mexico after seventeen years of use, already has 15 per cent of its storage capacity occupied by silt, which has depreciated the original construction cost of $4,536,000 to the extent of $680,000. The Roosevelt Reservoir in Arizona has been silting at a rate of approximately 7,800 acre-feet per annum, or about 0.5 per cent of the total capacity. The Boulder Dam will accumulate silt at a rate of not less than 196,000 acre-feet per annum. The average construction cost for an acre-foot of storage in Boulder Dam when completed will be about $3.00, or, in other words, approximately $580,000 of investment will be destroyed annually by silt deposits. By the end of the fifty years, when it is expected the original cost finally will have been paid, $29,000,000 of investment, in addition to the interest, will have been taken up by silt.

The West, thus, is faced with the reality of many huge engineering undertakings becoming the repositories of silt removed from the watersheds. It is true that a portion of this silt is the result of natural erosion, but there is abundant evi-

dence that erosion has been accelerated by depletion of plant cover on the watersheds.

The capacity of the soil to absorb and retain water depends in considerable measure upon the presence of humus or organic matter in the soil. If a forest is cut off and burned, if a field is allowed to lose its topsoil and the contained organic matter, the absorptive capacity of the soil is reduced.

Water falling on such soil runs off rapidly, picks up part of the soil surface and carries it to the streams as sediment.

The result is: farms lose fertility and soil, small streams are choked, streams are filled with mud, navigation on larger streams is made hazardous and costly, and, most important of all, the region becomes impoverished for water. The ground waters are lowered, wells dry up, and springs disappear. Even though annual precipitation remains constant, we may have what approaches a drought, because the natural cycle of water and soil relationship has been shortened and disturbed.

Under such a situation it is necessary to revert to the slow natural process of restoring a plant cover that will check further erosion and gradually build up the organic matter and other elements of which the soil has been robbed. Forest cover, where it can be grown, is considered the best for this purpose, first, because of its superior ability to add organic matter to the soil as compared with other wild vegetation, and second, because a forest cover, if protected against fire, insures a more stable tenure of conditions favorable to rehabilitation than does a brush or herbaceous cover.

It is for the conservation of the soil resource quite as much as the water resource or timber resource that the forester argues the need of protection forests. An entirely new and much more sane conception of the function of humus in water absorption by soils has been developed by research foresters, so that one no longer thinks of the humus layer as a reservoir in itself, but as supplying the channels through which water may penetrate an otherwise largely impermeable soil.

From studies made by forest officers in California it has been proved that the forest litter greatly reduces the superficial runoff, particularly in the finer-textured soils, and this influence continues long after the litter is completely saturated; that destruction of the litter by such agencies as fire and the consequent exposure of the soil greatly increases the amount of eroded material and reduces the absorption rate of the soil; that suspended particles in run-off water from bare soils are filtered out at the surface and seal the pores and seepage openings into the soil sufficiently to account primarily for the marked differences in rate of absorption between bare and litter-covered soils; and finally that the capacity of forest litter to absorb rainfall is insignificant in comparison with its ability to maintain the maximum percolating capacity of soil profiles.

The important point is to keep the water clear and usable. In southern California usable water is water that is devoid of silt load, and there it is impossible to use water that carries heavy silt. In that region very little of the water for irrigation purposes is used and applied directly. As in Honolulu, where 90 per cent of the total water supply is obtained from underground sources, so in southern California 90 per cent of the water is pumped from underground basins. There, after the mountains were uplifted, the valleys were filled by material eroded out of these

mountains. Flats in California usually are filled-up former valleys or basins, and these filled basins of coarse detrital material, sometimes over 2,000 feet deep, furnish ideal storage basins. This keeps water pure, prevents its waste by evaporation or transpiration, and makes water available wherever wells are put down for irrigation, without cost for construction of aqueducts and canals. The most economical means of utilizing the water yield from the mountain areas is to put it underground. Particularly is this so because the rains come in winter. The important thing is to get water underground and water cannot spread and sink underground if it contains a large amount of sediment in suspension. Nor can it be spread and sunk underground if it comes in a peak storm flow. Then it can only be wasted to the ocean and once wasted it is lost. There water is worth $20.00 per acre-foot, about four times the value of water in Honolulu. It does not take a peak flow very long to cause a loss of one million dollars' worth of water. One principal means of the conservation of water in California, in Hawaii, and in other places, is to keep that water in such condition that it can be sunk underground.

Yet, prominent mainland engineers by analyzing figures of water measurements from certain watersheds which are extreme in character of soil and climate have recently attempted to generalize and have argued against the protective value of the forest under all conditions and unfortunately local individuals have been foolish enough to be influenced by these assertions sufficiently to disparage the work of forest protection carried on in this Territory. Among the conclusions in the Hoyt and Troxell report are the statements that "Forests do not conserve the water supply" and that the forest cover lessens the summer flow. They based their arguments on areas in Colorado and California which were in no sense normal. They omitted many facts that are vital to any logical and sane discussion of the subject of forests and stream flow, of watershed protection, and of the general utilitarian value of forested versus bare lands. While their proposal is carefully guarded and qualified, it tends to leave the impression that sufficient facts have been established to warrant so radical a departure as the elimination of protective forest cover.

Their revolutionary scheme, brought to its logical conclusion, is to obtain a higher yield of water by means of the simple expedient of removing the vegetation from the watershed, and with that, eventually, the soil as well.

Foresters were the first to demonstrate that forests use water in large quantities, as I have already mentioned. The increase in summer flow on the deforested watershed in the Wagon Wheel Gap experiment in Colorado is relatively small and may be fully accounted for by reduced interception of summer rains, occasioned by a forest cover prior to deforestation. This finding is used, however, to support by analogy the finding of a higher percentage increase of summer flow in southern California. The relative amount of increase as compared to the total flow is only 4 per cent, a figure less than the degree of accuracy which can be claimed for the stream gagings. Yet it is the discovery of this small increase which furnishes the basis of the conclusions and for the deduction that "the maintenance of forests for conservation of the water supply may have an effect exactly opposite to that desired."

The lack of adequate analysis and evaluation of the several factors that account for relatively small increase of summer flow invalidates both conclusions and deductions of their report for application, not only in California, but to other regions

as well, and the report presents an amazingly unbalanced picture of the many-sided water problem in that state. The lamentable inadequacy of the report is shown by special emphasis on summer flow variations which comprise in the study less than 5 per cent of the total annual flow, whereas problems affecting conservation of from 95 to 99 per cent of annual stream discharge are omitted from consideration.

As has already been pointed out, the principal method of conservation of water there is to sink storm run-off into underground detrital-filled basins. Water conditions necessary for maximum percolation of storm flow into underground basins are regulated flow and freedom from silt. With the burning or destruction by other means of the forest cover as advocated by these engineers, neither of these two conditions would be obtained for handling the greater part of the rainfall. Unregulated and muddy flood waters waste to the ocean and are permanently lost to use. We see this happen right here in our own islands.

The mantle of chaparral vegetation on the hills of southern California proves to be the most effective ally in regulating storm flow as well as in safeguarding costly flood storage capacity. Chief Engineer Eaton, of the Los Angeles County Flood Control District, places the value of chaparral cover above that of check dams and flood control dams. He states, "This normal mountain vegetation is the most effective and economical agency in the regulation of flood flows, increasing percolation and preventing erosion." And this is why the people of southern California spend millions in protecting this beneficial cover against destruction by fire or other agencies.

The time has not yet arrived when man may assume the audacity to start reversing the great constructive processes of Nature, for the sake of a temporary benefit, to water a few paltry additional acres of crops or to permit a few more people to congregate in the cities at the expense of increasing the flood run-off from burned watersheds, wastage to the ocean because of the silt load, consequent accelerated erosion, and damages to streets, bridges, railways, highways, orchards and other property. Losses of storm run-off from burned watersheds may exceed many fold total summer flow.

The beneficial value of our native forests on the water supply was recognized in Hawaii as far back as 1892, when the Hawaiian Kingdom passed Chapter 74, approved by Queen Liliuokalani on December 19, 1892. The preamble to the "Act to Exempt Certain Forest Lands from Taxation" reads as follows:

> WHEREAS, the preservation of the Forests is a matter of great public interest in consequence of their influence upon the water supply of the Kingdom. . .

The faith of the informed and observing people of the Territory in the value of forests because of their beneficial influence on the water supply has remained unshaken and this faith is manifested in the progress that has been made during the past quarter of a century in protecting unspoiled, native forest areas and reclaiming other areas on which the native forest has been destroyed by the zeal of ranching and agricultural industries in developing to their limit without any consideration for the perpetuation of the water supply. We have progressed to the extent of setting apart for watershed forests 1,027,299 acres, or about 25 per cent of the total land area of the Territory. We are now reforesting the open areas in this important forest estate at the rate of 30,000 trees per month and during the past

seventeen years have planted up 6,427 acres, which is only 24 per cent of the areas that are in need of immediate attention. Excessive erosion detrimental to the water supply is imperceptibly but surely taking place on some of our watersheds, and as long as this continues and as long as we have floods like that of 1930 in Kalihi Valley, which took a toll of eleven human lives, and have the effects of the mauka storms of 1923 and 1924 in Hamakua, when $95,000 damage was done to county roads and bridges alone, not to mention inestimable damage to the top soil by scouring and leaving a hardpan incapable of supporting even the poorest of weeds, we are still behind on our program of protecting properly our soil and water resources through forest extension.

The need for this class of work on the mainland, where soil erosion is lessening the productiveness of farms, causing disastrous floods, and interfering with hydro-electric development and with river navigation, has been recognized by our new President in Washington and in his good judgment he has seen fit to give forest work first attention as being necessary for the nation. His civilian conservation corps selected from the unemployed is today being recruited and trained by the army in camps to reforest national and state lands, to prevent soil erosion, and to put in fire and flood prevention improvements.

Water supply, floods, erosion and worn out soils—these are problems of the farm, the city, the county, the state and the nation. For many years forestry and forest lands have been recognized for wood, forage, outdoor recreation and beneficial influences upon water and soil. The recognition of water and soil problems in forest policy has been scarcely more than nominal. A good deal has been said but relatively little has been done in a real concrete way to give the water and soil problems the attention their importance warrants as a public responsibility. After all, the watershed problem is more a public responsibility than any other problem in the conservation of wild lands.

Once the few fundamental facts about erosion are understood, the remedies become perfectly clear. The situation is simply this: there is only one fundamental way to control navigation and regularity of streams and to maintain normal climatic conditions and abundant crops, and that is by retaining in the ground itself as much as possible of the precipitation falling on the ground, and by retarding as much as possible its run-off from the surface of the soil.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 20, 1933, TO SEPTEMBER 8, 1933.

Date	Per Pound	Per Ton	Remarks
June 20, 1933	3.36¢	$67.20	Puerto Ricos.
" 23	3.40	68.00	Puerto Ricos.
" 27	3.50	70.00	Puerto Ricos.
" 30	3.30	66.00	Cubas.
July 5	3.49	69.80	Puerto Ricos, 3.48, 3.50.
" 6	3.50	70.00	Puerto Ricos.
" 11	3.565	71.30	Cubas, 3.55, 3.58.
" 12	3.65	73.00	Philippines, Cubas.
" 19	3.60	72.00	Cubas.
" 21	3.50	70.00	Cubas.
Aug. 1	3.45	69.00	Cubas.
" 16	3.44	68.80	Cubas.
" 24	3.56	71.20	Cubas.
Sept. 6	3.635	72.70	Philippines, 3.65; Cubas, 3.62.
" 8	3.61	72.20	Cubas.

INDEX TO VOLUME XXXVII

(An asterisk preceding a page number indicates that the subject is illustrated.)

A

Agee, H. P., P. O. J. 36 on Hawaii..... 3
Agriculture, prehistoric, in Hawaii..... 125
Ahupuaas 129
Annual synopsis of mill data—1932..... 67
Armyworms—
  control of, with arsenical dust..... 5
  parasite of ..... * 168
  poison bait for..... 87
Arsenical dust for armyworm control..... 5
Artesian well (Ashley's).....145, * 146
Ashley, J. 145
Auwai's 127, 130
Ayres, Arthur, variation of mineral content of cane with age and season... * 197

B

Bait—
  poison, for armyworms and cutworms 87
  rat 96
Baldwin and Alexander ditch..... 144
Bindweed ..... * 19
Biology of *Telenomus nawai* Ashm..... * 168
Borden, R. J., a basic fertilizer plan and schedule ..... * 178
Bufo marinus, introduction to Hawaii... * 15

C

Campbell, James 145
Canals—
  ancient 127
  early 141
  Kekaha-Waimea 154
  Olokele 151
  Waihee 158
Cane—
  annual synopsis of mill data—1932.. 67
  chromosomes of ..... * 26
  growth, in relation to temperature and light intensity ....* 32, * 53, * 97, 174
  history of early culture..... 136
  invertase studies 13
  irrigation, see irrigation.
  juices, see juices.
  lime experiments 17
  pests, see pests.
  quality ratio, annual synopsis mill data 67
  rate of cane and sugar formation... * 88
  seedlings on Kauai 6
  soils, physical constants ..... * 106
  variation of mineral content with age and season ..... * 197
  varieties, see varieties.
Caum, E. L., bindweed..... * 19
Charts, weather, for plantation use..... * 97
Chinese grasshopper, *Oxya chinensis*, (Thun.) introduction of egg parasite * 7
Chromosomes of sugar cane..... * 26
Clark, Byron O. 148
Climate, effect on cane growth..... .....* 32, * 53, *97, 174
Commission—
  land 139
  water 139, 141
Constants, physical, for Hawaiian soils.. * 106
Convolvulus arvensis Linn. ..... * 19
Cutworms, poison bait for..... 87

D

Dams—
  McBryde Sugar Co..... 158
  Wahiawa 153
Das, U. K.—
  how to measure temperature in terms of day-degrees 174
  measuring production in terms of temperature ..... * 32
  rate of cane and sugar formation in cane crop ..... * 88
Ditch lining .....127, * 128, * 149, 160
Ditches—
  ancient 125, 127, 129
  Baldwin and Alexander..... 144
  Hamakua 144
  Hanapepe 147
  Kauhikoa ..... * 157
  Koolau 151
  Lowrie 151
  Menehune .....127, * 128
  Olokele 152
  Rice 141
  Spreckels 145
  Waiahole ..... * 156
  Wailoa 156
  Waimanalo ..... * 149
Doty, R. E., use of thallium torpedoes.... 96
Dust, arsenical, for armyworm control.... 5

E

Eckart, R. C., effect of light intensity on growth of H 109..... * 53
Egg parasites—
  of Chinese grasshopper..... * 7
  of the armyworm..... * 168
Equipment on plantations—
  irrigation devices .....* 92, * 124
  scales 10
  weather charts ..... * 97
Ewa Plantation Co.....
  * 147, * 149, 150, * 152, * 153, * 154
  temperature and cane growth records * 32
Experiments—
  invertase studies of sugar cane..... 13
  lime mortar and molasses..... * 113
  lime versus no lime..... 17
  pot, surface feeding of phosphate.... 187
  rate of cane and sugar formation.... * 88
  temperature effect on cane growth.. ..... * 32, * 53
  variation of mineral content of cane with age and season..... * 197

F

Fertilizer—
  a basic plan and schedule..... * 178
  lime versus no lime..... 17
Fixation, phosphate, in Hawaiian soils... 182

G

Gow, P. L., phosphate surface feeding.... 187
Grasshopper, Chinese, introduction of egg parasite ..... * 7

H

H 109, see varieties.
Hamakua ditch 144
Hanapepe ditch 147
Hance, Francis E., phosphate fixation in Hawaiian soils 182
Haole 134
Hartt, Constance E., studies of the invertase of sugar cane..... 13
Hawaii, P. O. J. 36 areas..... 3
Hawaiian Sugar Co..... 147
Hinman, C. P., scales and their troubles . 10
History—
  irrigation in Hawaii..... * 124
  sugar in Hawaii..... 136
Honokaa Sugar Co., temperature and cane growth records ..... * 32
Honolulu Sugar Co..... 150

I

Insects—
  see armyworm.
  see cutworm.
  see grasshopper.
Invertase of sugar cane, studies..... 13
Irrigation methods, early 158

Irrigation—
early ... 141
early history ... * 124
pineapple ... * 138, 148
prehistoric ... 125
water stage register for field ditches. * 92

J

Jorgensen, J. ... 155
Judd, Charles S., water ... 207
Juice, cane—
annual synopsis of mill data—1932. 67
quality in lime experiments ... 17

K

Kahuku Plantation Co. ... 147
Kauai—
early irrigation methods ... 141
seedling propagation on ... 6
Kauhikoa ditch ... * 157
Kekaha Waimea canal ... 154
Keppeler, J. P. ... 148
Konohiki rights ... 132
Koolau ditch ... 151
Kuleanas ... 129

L

LaGuardia, Mayor, on research ... 167
Land—
commission ... 139
division or mahele ... 124, 136, 140
Lava tube tunnels ... 152
Laws, water ... 132, 139, 140, 141
Lennox, C. G., notes on seedlings, Kauai. . 6
Light intensity, effect on cane growth * 32, * 53
Lime—
mortar, addition of molasses for strength ... * 113
versus no lime experiments ... 17
Lippencott, J. B. ... 155
Lowrie ditch ... 151

M

Mahele or land division ... 124, 136, 140
Mangelsdorf, A. J., chromosomes of sugar cane ... * 26
Martin, J. P., effect of light intensity on growth of H 109 ... * 53
McAllep, W. R., annual synopsis of mill data—1932 ... 67
McBryde Sugar Co., dam ... 158
McCleery, W. L., annual synopsis of mill data—1932 ... 67
Menehune ditch ... 127, * 128
Mill data, annual synopsis of ... 67
Mineral content of cane, variation with age and season ... * 197
Miner's inch ... 153
Molasses, use of in lime mortar ... * 113
Mongoose, food habits ... * 12
Mortar, lime, addition of molasses for strength ... * 113

N

Nakuina, Emma M. ... 129
Nematode ... 136

O

Oahu Sugar Co. ... 150
Olokele canal or ditch ... 151, 152
O'Shaughnessy, M. M. ... 151
Oxya chinensis (Thun.) ... * 7

P

Parasites—
armyworm ... * 168
grasshopper ... * 7
Pemberton C. E.—
food habits of mongoose ... * 12
improved arsenical dust for armyworms ... 5
introduction of egg parasite of Chinese grasshopper ... * 7
introduction to Hawaii of toad *Bufo marinus* ... * 15
notes on biology of *Telenomus nawai*, parasite of armyworm ... * 168
poison bait for armyworms and cutworms ... 87
Pepeekeo Sugar Co. temperature and cane growth records ... * 32
Pests of sugar cane—
armyworms, control by arsenical dust and poison bait ... 5, 87
armyworms, control by parasites ... * 168
bindweed ... * 19
Chinese grasshopper, egg parasite ... * 7
cutworms and armyworms, control by poison bait ... 87
rats, poison bait for ... 96
Phosphate fixation in Hawaiian soils ... 182
Pineapple irrigation ... * 138, 148
Planting methods ... 158
Plan and schedule for fertilizer ... * 178
Plantation equipment, see equipment.
Poison—
bait, for armyworms and cutworms .. 87
dust, for armyworm control ... 5
torpedoes, for rats ... 96
P. O. J. 36, see varieties.
P. O. J. 2878, see varieties.
Pot experiments, surface feeding of phosphate ... 187
Predatory toad, *Bufo marinus*, introduction to Hawaii ... * 15
Prehistoric agriculture and irrigation ... 125
Prices of sugar—
Sept 21, 1932—Dec. 15, 1932 ... 84
Dec. 17, 1932—Mar. 15, 1933 ... 122
March 21, 1933—June 13, 1933 ... 163
June 20, 1933—Sept. 8, 1933 ... 219
Propagation of seedlings on Kauai ... 6

Q

Quality ratio—
annual synopsis of mill data—1932 67
lime experiments ... 17

R

Rainfall, measurement on plantations ... * 97
Rats, poison baits for ... 96
Register, water, for field ditches ... * 92
Research, Mayor LaGuardia ... 167
Rice ditch ... 141
Rodent control ... 96

S

Scales, use on plantations ... 10
Schedule and plan for fertilizer ... * 178
Seedlings on Kauai ... 6
Soils—
phosphate fixation in Hawaiian ... 182
physical constants ... * 106
Spodoptera mauritia (Boisd.) ... * 168
Spreckels ditch ... 145
Sugar—
cane, early culture in Hawaii ... 136
cane, effect of temperature and light intensity on growth ... * 32, * 53, * 97, 174
cane irrigation, see irrigation.
cane, soils, physical constants ... * 106
cane, variation of mineral content with age and season ... * 197
prices ... 84, 122, 163, 219
rate of cane and sugar formation ... * 88
yield, annual synopsis of mill data—1932 ... 67
Sunshine, effect on cane growth ... * 32, * 53, * 97, 174
Surface feeding of phosphates ... 187
Swezey, J. A., effect on the strength of lime mortar by addition of molasses .. * 113

T

Taro culture, early.....125, 132, * 133, * 135
Telenomus nawai Ashm. ..... * 168
Temperature—
charts for plantation use..... * 97
effect on cane growth...* 32, * 53, 174
how to measure in terms of day-degrees 174
Thallium, use of in poison bait..... 96
Toad, *Bufo marinus*, introduction to Hawaii ..... * 15
Torpedoes, thallium, for rat bait..... 96
Tunnels—
early 127
lava tube 152
Waiahole 155
Tylenchus 136

V

Variation of mineral content of cane with age and season ..... * 197
Varieties of sugar cane—
annual synopsis of mill data—1932.. 67
H 109, effect of light intensity on growth ..... * 53
H 109, invertase studies..... 13
H 109, effect of temperature..... * 32
H 109, rate of cane and sugar formation ..... * 88
H 109, variation of mineral content with age and season..... * 197
P. O. J. 36 areas on Hawaii..... 3
P. O. J. 2878, invertase studies.... 13
seedlings on Kauai 6
Verret, J A., lime versus no lime..... 17

W

Wadsworth, H. A.—
history of irrigation in Hawaii..... * 124
physical constants for Hawaiian soils * 106
water stage register for plantation field ditches ..... * 92
Wahiawa dam 153
Waiahole—
ditch ..... * 156
tunnel 155
Water Co. 155
Waialua Agricultural Co. 150
Waihee canal 153
Wailoa ditch 156
Wailuku Sugar Co. ..... * 151, 153
Waimanalo ditch ..... * 149
Ward, R. R., phosphate surface feeding. 187
Water— 207
commission 139, 141
laws and rights 132, 139
register for field ditches.. ..... * 92
see climate.
see irrigation.
see rainfall.
see weather.
see wells.
Weather—
charts for plantation use..... * 97
effect on cane growth.. * 32, * 53, 174
see temperature.
Weights, scales for on plantations..... 10
Weller, D. M., chromosomes of sugar cane * 26
Wells, early .....145, * 146
Williams, W. L S., weather charts for plantation use ..... * 97
Wise, John 134

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

OFFICERS FOR 1933

J. E. RUSSELL ..... President
JOHN WATERHOUSE ..... 1st Vice-President
R. A. COOKE ..... 2nd Vice-President
R. D. MEAD ..... Additional Vice-President
J. K. BUTLER ..... Secretary and Treasurer, and Director of Labor Bureau
S. O. HALLS ..... Asst. Secretary and Asst. Treasurer
W. PFLUEGER ..... Asst. Secretary
J. W. WALDRON ..... Auditor

TRUSTEES FOR 1933

H. A. WALKER
J. W. WALDRON
R. A. COOKE
F. C. ATHERTON
J. E. RUSSELL
JOHN WATERHOUSE

EXPERIMENT STATION COMMITTEE

J. W. WALDRON, Chairman

C. R. HEMENWAY
T. H. PETRIE
J. E. RUSSELL
H. A. WALKER
J. H. MIDKIFF
L. D. LARSEN

EXPERIMENT STATION STAFF

H. P. AGEE ..... Director

R. C. L. PERKINS, OTTO H. SWEZEY ..... Consulting Entomologists
C. E. PEMBERTON ..... Executive Entomologist
Associate Entomologists: F. X. WILLIAMS, R. H. VAN ZWALUWENBURG.
Asst. Entomologist: FRED A. BIANCHI.

H. L. LYON ..... Botany and Forestry, in charge
Forest Supervisors: L. W. BRYAN (Hawaii), GEORGE A. McELDOWNEY (Oahu), ALBERT DUVEL (Kauai). Assistant Botanist: E. L. CAUM. Research Assistant: HUGH W. BRODIE. Assistant in Forestry: COLIN POTTER.

W. R. McALLEP ..... Sugar Technologist
Associate Sugar Technologist: W. L. McCLEERY. Assistant Sugar Technologist: RAYMOND ELLIOTT. Technical Chemist: A. BRODIE. Associate Chemists: H. A. COOK, FRED HANSSON. Assistant Chemists: COURTLAND ASHTON, WARD S. FLESHMAN.

F. E. HANCE ..... Chemist
Associate Chemists: L. E. DAVIS, F. RAY VAN BROCKLIN. Assistant Chemists: ARTHUR AYRES, PAUL GOW.

J. A. VERRET ..... Consulting Agriculturist
A. J. MANGELSDORF ..... Geneticist
RALPH J. BORDEN ..... Associate Agriculturist
Assistant Agriculturists: Y. KUTSUNAI, F. C. DENISON, H. K. STENDER, R. E. DOTY, ROYDEN BRYAN (Hawaii), O. H. LYMAN (Maui), J. N. P. WEBSTER (Kauai), A. H. CORNELISON, COLIN G. LENNOX (Assistant Geneticist), U. K. DAS, DOUGLAS A. COOKE (Plant Physiologist).

H. L. LYON ..... Consulting Pathologist
J. P. MARTIN ..... Pathologist
Associate Pathologist: C. W. CARPENTER. Histologist: D. M. WELLER.

W. TWIGG-SMITH ..... Illustrator
MABEL FRASER ..... Librarian

TABLE OF CONTENTS

Page

P. O. J. 36 on the Big Island 3

Improved Arsenical Dust for Armyworms 5

Notes on Seedlings—Kauai 6

Introduction to Hawaii and Habits of Egg Parasite of Chinese Grasshopper 7

Scales and Their Troubles 10

Some Food Habits of the Mongoose 12

Studies of the Invertase of Sugar Cane 13

Introduction to Hawaii of the Tropical American Toad *Bufo marinus* 15

Lime Versus No Lime 17

The Bindweed 19

Chromosomes of Sugar Cane 26

Measuring Production in Terms of Temperature 32

The Effect of Various Intensities of Light on the Growth of the H 109 Variety of Sugar Cane 53

Annual Synopsis of Mill Data 67

Sugar Prices 84

Poison Bait for Armyworms and Cutworms 87

Rate of Cane and Sugar Formation in a Cane Crop 88

An Inexpensive Water Stage Register for Use on Plantation Field Ditches 92

Some Notes on the Use of Thallium Torpedoes 96

Weather Charts for Plantation Use 97

Some Physical Constants for Certain Hawaiian Sugar Cane Soils 106

Investigation of the Effect on the Strength of Lime Mortar by the Addition of Molasses 113

Sugar Prices 122

A Historical Summary of Irrigation in Hawaii....124

Sugar Prices....163

Mayor LaGuardia on Research....167

Notes on the Biology of *Telenomus nawai* Ashm....168

How to Measure Effective Temperature in Terms of Day-Degrees....174

A Basic Fertilizer Plan and Schedule....178

Phosphate Fixation in Hawaiian Soils....182

Variation of Mineral Content of Sugar Cane with Age and Season....197

Water....207

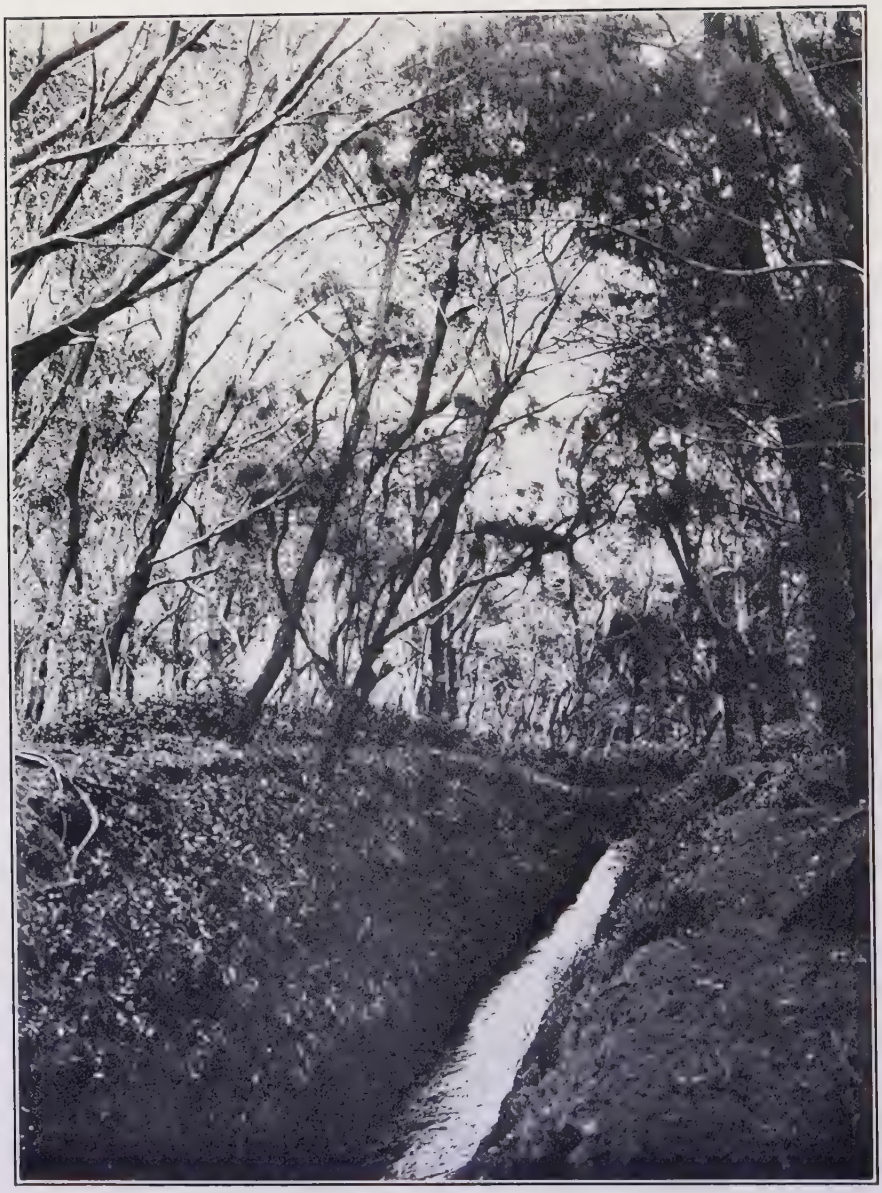
Sugar Prices....219

ILLUSTRATIONS APPEARING ON THE COVERS OF VOLUME XXXVII

FIRST QUARTER

BUFO MARINUS
Tropical American Toad
Introduced into Hawaii from Porto Rico in April, 1932.

Two of the new hybrids between H 109 and P. O. J. 2878.



The historical irrigation ditch built by W. H. Rice at Lihue in 1856. At present, considerably enlarged, this ditch, through the German Forest, follows the route of the first irrigation canal for sugar cane in Hawaii. (Original photograph taken about 1885; courtesy of Miss Ethel M. Damon and Mrs. Dora H. Isenberg.)

FOURTH QUARTER

Breeding Canes in Tassel—Kailua Variety Station.